PB81-172645

Limestone-Lime Treatment of Acid Mine Drainage - Full Scale

Peabody Coal Co.
St. Louis, MO

Prepared for

Industrial Environmental Research Lab.
Cincinnati, OH

Mar 81

U.S. Department of Commerce
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1. REPORT NO. EPA-600/7-81-033	2.	3. RECIPIENT'S ACCESSION NO. PB81 172645
4. TITLE AND SUBTITLE LIMESTONE - LIME TREATMENT OF ACID MINE DRAINAGE - FULL SCALE		5. REPORT DATE March 1981
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) David G. McDonald Alten F. Grandt		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Peabody Coal Company 301 North Memorial Drive St. Louis, Missouri 63102		10. PROGRAM ELEMENT NO. N141E
		11. CONTRACT/GRANT NO. 14010 DAX
12. SPONSORING AGENCY NAME AND ADDRESS Industrial Environmental Research Laboratory US Environmental Protection Agency Cincinnati, OH 45268		13. TYPE OF REPORT AND PERIOD COVERED Final: 10/68 - 10/77
		14. SPONSORING AGENCY CODE EPA600/12

15. SUPPLEMENTARY NOTES

16. ABSTRACT

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Considerable effort has been expended in investigating the neutralization of acid mine drainage with limestone, lime, and soda ash. A combination limestone-lime process has been shown to have cost advantages with improved effluent quality and sludge settling characteristics. Peabody Coal Company, in cooperation with the U.S. Environmental Protection Agency, designed, constructed, and operated a full scale treatment plant to study the process.

This document is the final and summary report on the neutralization studies. Work on the project was conducted according to a joint Peabody Coal Company/Stanley Consultants proposal to the Environmental Protection Agency. Experimental work was conducted during the period March 1973 to February 1974.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Acid Mine Drainage Coal Mining	Surface Coal Mining Acid Neutralization Treatment Plants Water Treatment	

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES 204
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EPA 600/7-81-033
March 1981

PB81-172645

LIMESTONE-LIME TREATMENT OF ACID MINE DRAINAGE - FULL SCALE

by

David G. McDonald and Alten F. Grandt
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Project No. 14010 DAX

Project Officers

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ABSTRACT

Utilizing a full scale neutralization plant, the effect of detention time, sludge recirculation, flow pattern, and treatment pH have been observed using limestone and lime separately and in combination. Data have been accumulated on highly acidic ferric iron acid mine drainage to determine the most economical method of treatment.

Plant operation indicates that combination limestone-lime treatment with sludge recirculation on both treatment lines is the most economical scheme of treatment.

Lime treatment in series flow eliminated up to 85% of the metal cations in the plant influent, however, addition of less desirable species, i.e. chromium, lead, etc., is well documented.

Sludge studies indicate limestone treatment to high pH levels yielded sludges with the highest solids content. Sludges of slightly lower solids content were acquired during series flow treatment of similar AMD with lime and sludge recirculation.

This report is submitted in fulfillment of Project Number 14010 DAX under the partial sponsorship of the Industrial Environmental Research Laboratory, U.S. Environmental Protection Agency, and the Peabody Coal Company.

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report contains a study of combination limestone - lime treatment of acid mine drainage from coal mine areas. This report is intended for both government and industry use, and attempts to relate the effectiveness of limestone and lime, used separately and in combination, to treat acid mine drainage. Further information on this subject may be obtained from the Oil Shale and Energy Mining Branch, Energy Pollution Control Division.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

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ACKNOWLEDGMENTS

Work on this project was supervised by Mr. Alten F. Grandt, Director of Reclamation, who functioned as Project Director, and Mr. Harry Yocum, Reclamation Department Supervisor for Peabody Coal Company's Southern Illinois area, who served as Field Director for the project.

Research chemists who performed laboratory analyses and directed plant operations during research were David G. McDonald, Sr., Environmental Quality Department, Peabody Coal Company, and Frances Harding, chemist, Peabody Coal Company.

Peabody's Central Laboratory personnel involved in spectrophotometric work were James Addington, laboratory manager; Steven Burns and Richard Wilburn, chemists; and Cora Merrill and Ron Cross, technicians. The helpful suggestions and comments of Max Orem, Project Officer through 1971; John Martin, Project Officer from 1972 to completion of the project; and Ronald Hill, Director of the Resource Extraction and Handling Division, U.S. Environmental Protection Agency, were sincerely appreciated.

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SECTION 1

INTRODUCTION

GENERAL BACKGROUND OF PROJECT

The nation-wide problems related to acidic discharges from coal mining operations are well documented in both popular and technical literature. Neutralization is and will continue to be a necessary short-term measure in numerous instances, while long-range programs are being developed to prevent and/or arrest acid production at the source.

Considerable effort has recently been expended in investigating the neutralization of acid mine drainage with limestone, lime, and soda ash. Studies have pointed out the advantages and disadvantages of each neutralizing process in relation to cost of treatment, nature of sludges produced, quality of effluent, etc. A combination limestone-lime process has been shown to have cost advantages with improved effluent quality and sludge settling characteristics. However, no work has been performed on the combination process on a full plant scale basis. Peabody Coal Company, in cooperation with a grant from the U.S. Environmental Protection Agency, designed, constructed, and operated a full scale treatment plant to study the process.

This document is the final and summary report on the neutralization studies. Work on the project was conducted according to a joint Peabody Coal Company/Stanley Consultants proposal to the Environmental Protection Agency. Experimental work contained in this paper was conducted during the period March 1973 to February 1974.

OBJECTIVES

Long-range objectives of the project included the following:

1. To add to current technology regarding techniques of neutralization of large volumes of acid mine drainage, utilizing limestone alone and in combination with lime.

2. To operate a full scale neutralization plant to treat acidic discharges from the Will Scarlet Mine in an attempt to develop techniques of treatment to optimize neutralization efficiency and minimize operating costs.

3. To publish background studies, operational information, and final results in a form usable to all parties confronted with an acid mine drainage problem. It is not an objective of this study to develop water quality standards relating to effluent discharging from the neutralization plant or to imply that such a facility should become a standard part of coal mining operations.

Objectives of the study covered by this report were:

1. To determine the most economical method of treatment of highly acidic mine drainage in large volumes.

2. To observe and report effectiveness of acid mine drainage treatment, with special emphasis on metal ion removal.

3. To characterize sludges from treatment processes as to settling behavior and solids contents.

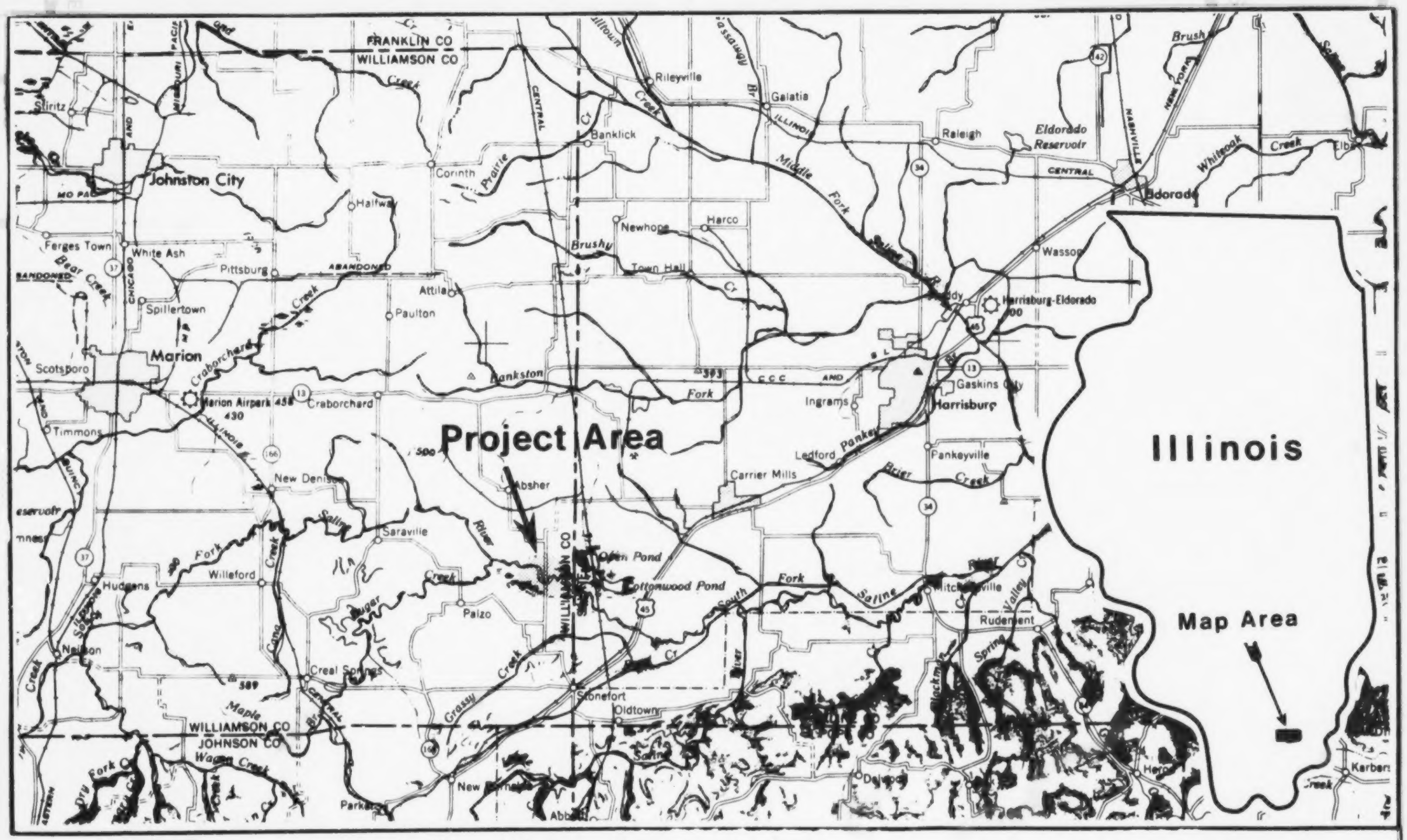
NATURE AND SCOPE OF THE PROBLEM

The Will Scarlet Mine is an active coal-producing mine located approximately 3 miles southwest of Carrier Mills, Illinois, in Saline and Williamson Counties (Figure 1). Mining operations were started at Will Scarlet by the Stonefort Coal Company in 1953. Peabody Coal Company purchased the mine in 1967 and is presently operating at a current production of 2,268 metric tons (2,500 tons) of coal per day.

Before construction and operation of the full scale treatment plant, acid mine runoff from old surface works was diverted into inactive surface mine pits. Even with construction of extensive dike systems and relocation of the South Fork of the Saline River, the major waterway, incidental pollution occurred during periods of river overflow, as well as seepage and surface runoff, and thus allowed some acidic water to enter the river. Within Peabody property, the problem was generally concentrated in an area of slightly more than 809 hectares (2,000 acres) south and southwest of the active coal field, with an estimated backlog of 1.8×10^9 gallons (6.8×10^9 liters) of acid mine water in pits (Figure 2).

The source of the acid drainage was surface spoil materials that resulted from mining of partings and overburden associated with the Davis and DeKoven coal seams. As mining operations moved to the west, the interval between coal seams was smaller, thus reducing the volume of acid-producing spoil, which contained large amounts of readily oxidizable pyritic materials.

Even with a vigorous acid mine drainage abatement program, which included minor grading and channeling improvements, it was necessary to channel all acid-contaminated water to a central location near Pit #10 for neutralization treatment before discharge to the South Fork of the Saline River. This interim solution would provide relief from the problem of acid mine drainage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Cottonwood Pond
Saline River
Middle Fork
South Fork
Brushy
Bankston Fork
Pankey
Brier Creek
Grassy Creek
Sugar Creek
Crab Orchard Creek
Bear Creek
Prairie
Whiteoak Creek
Blackman
Spring Valley
Maple
Wagon Creek
Dry Fork
CENTRAL
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Figure 1 General Vicinity Map – Project Area

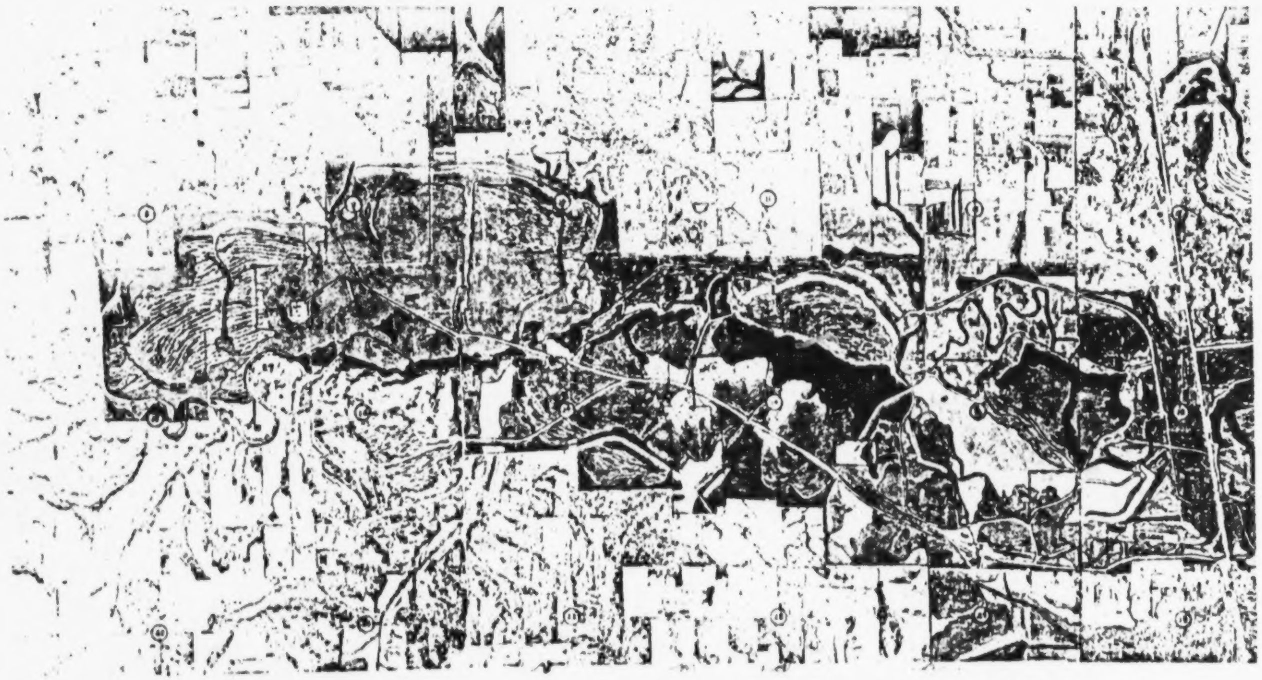

Figure 2 General vicinty map – drainage pattern

while permanent reclamation measures were being continued to provide at-source inhibition of acid production. The site also lent itself to the development of a full scale neutralization plant for evaluating various schemes of treatment.

Acidity, iron concentrations, and p^H of water in each of the major pits is indicated in Table 1. These pits were the source of feed water during the research period. Extremely high acidities illustrated the magnitude of the problem facing Peabody Coal. These samples were taken from the surface of respective pits. Samples collected at depths of 15 and 30 feet (4.6 m and 9.1 m) in several strip-pit lakes, yielded acidity values several times as great as at the surface and in one instance values as high as 32,000 mg/l acidity as $CaCO_3$ were observed, (Koehrsen and Grandt, 1970).

Water quality of the plant influent varied with the amount of rainfall. With increasing amounts of precipitation, dilution of the plant influent was observed but was preceded by a flushing of more acidic influent water. The range of water quality observed in the plant influent is shown in Table 2. Small concentrations of ferrous iron were observed during the research period, usually associated with periods of heavy rainfall and seepage from the slurry lagoon next to the plant influent channel.

APPROACH TO THE PROBLEM

A neutralization process for coal mine drainage entails a series of individual units of operation. This design, however, is limited to one straight-line treatment system. Thus, to incorporate series treatment (with the potential for increased detention time) and combination treatment, the design of the Will Scarlet Water Treatment Plant consists of two identical systems of individual units with recirculation capabilities (Figure 3).

For influent water containing ferric sulfate ($Fe_2(SO_4)_3$) and sulfuric acid (H_2SO_4), overall neutralization reactions for the respective chemical agents are as follows:

Lime, $Ca(OH)_2$:

$$Ca(OH)_2 + Fe_2(SO_4)_3 + H_2SO_4 \rightarrow CaSO_4 + Fe(OH)_3 + H_2O$$

Limestone, $CaCO_3$:

$$CaCO_3 + Fe_2\ (SO_4)_3 + H_2SO_4 \rightarrow CaSO_4 + Fe(OH)_3 + H_2O + CO_2$$

Limestone and Lime Combination:

$$CaCO_3 + Ca(OH)_2 + Fe_2(SO_2)_3 + H_2SO_4 \rightarrow CaSO_4 + Fe(OH)_3 + H_2O + CO_2$$

Products of reactions were gypsum ($CaSO_4 \cdot 2H_2O$), ferric hydroxide ($Fe(OH)_3$) and carbon dioxide (when limestone was used).

To determine the most economical method of treatment, observe chemistry of treatment and sludge characteristics and thereby achieve stated objectives

TABLE I, WATER QUALITY OF IMPOUNDED ACID MINE DRAINAGE (Koahrsen and Grandt, 1970)

Mine pit no.*	pH Range	Total acidity (mg/l as $CaCO_3$)	Total iron (mg/l as Fe)	Estimated+ volume (gal)
1	2.5 - 2.7	1,380 - 8,490	1-75	6.4×10^7
2	2.7	2,330 - 2,760	1	1.04×10^8
3	2.4 - 2.6	12,380 - 13,360	315 - 1,200	1.08×10^8
4	2.5 - 2.6	11,950 - 14,740	1,000 - 2,400	3.05×10^8
9	2.7	1,470 - 1,620	130 - 150	5.8×10^8
10	2.9 - 3.0	620 - 660	8 - 35	1.76×10^8

* See Figure 2 for location of pits. To convert from gallon to liters, multiply by 3.785.

+ Stanley Consultants, 1968.

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TABLE 2 RANGE OF WATER QUALITY OF PLANT INFLUENT

Parameter	Range
pH	2.4 - 3.1
Acidity*, b.p. to pH 8.3	1700 - 9200
Acidity,* cold with H_2O_2 to pH 7.3	1500 - 8500
Alkalinity*, to pH 4.5	0 - 93
Specific conductivity+	2800 - 7900
Iron, total, ppm	145 - 1130
Iron, ferrous, ppm	0 - 65
Iron, ferric, ppm	145 - 1070
Sulfate, ppm	2200 - 6600

* ppm as $CaCO_3$

+ μmhos/cm at 25C

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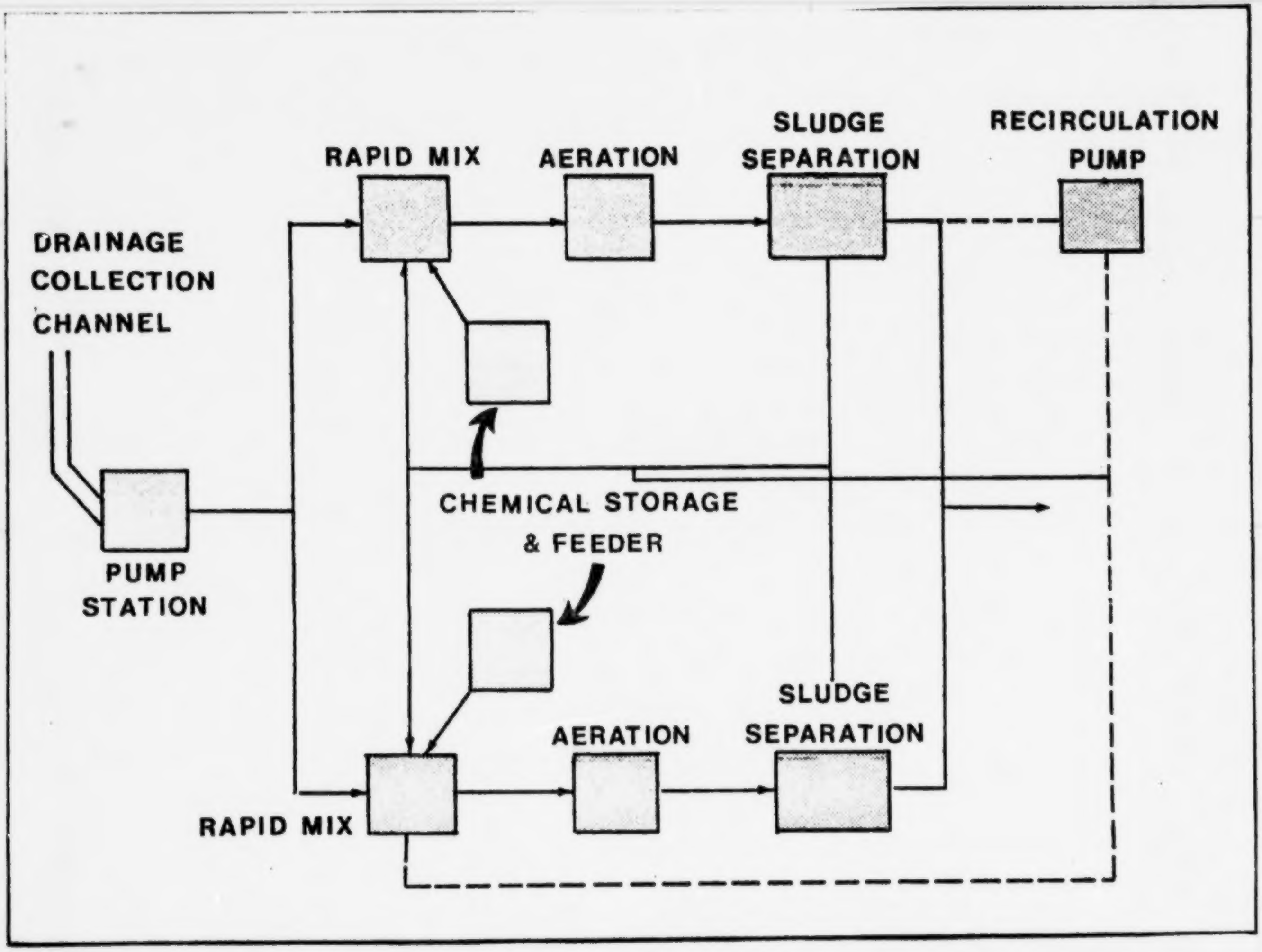
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SLUDGE
SEPARATION
RECIRCULATION
PUMP
CHEMICAL STORAGE
& FEEDER
RAPID MIX
AERATION
SLUDGE
SEPARATION

Figure 3 Flow diagram of Will Scarlet treatment plant

of this research program, work was conducted according to the research schedule (Table 3). The following factors of treatment were considered in the design of the schedule.

pH

In an attempt to determine effects of neutralization of acid mine drainage, Research Stages 1 thru 11 were designed to observe the effects of treatment at various pH levels with lime and limestone without sludge recirculation in parallel and series flow patterns. Further, stages 2-5 also afforded opportunity to observe the effects of lime and limestone (and the differences thereof) on the same plant influent during parallel flow, thus making a number of comparisons possible.

DETENTION TIME

Though Research Stages 2,8,14,15,21 and 22 were specifically designed to observe the effects of detention time on a specific neutralization scheme, this facet of treatment was generalized over a number of research stages, especially in relation to flow pattern.

SLUDGE RECIRCULATION

Research Stages 10 thru 24 were designed to observe the effects of sludge recirculation, as well as other facets of treatment. Variation of this operational factor included no sludge recirculation, sludge recirculation on line No. 1 only, and sludge recirculation on both treatment lines.

AERATION

The effects of aeration on the neutralization process were observed in Research Stages 8 and 9.

LIMESTONE

The limestone used in this study was obtained from the Fredonia Limestone Quarry, Fredonia, Kentucky. In order to obtain the smallest particle size commercially available, only the rock-dust form of limestone was used.

Table 4 presents the manufacturer's chemical analysis of the limestone dust costing \$9.00 per ton delivered (\$8.16 per metric ton) or 0.46¢ per lb (1.01¢ per Kg.).

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TABLE 3 WILL SCARLET WATER TREATMENT PLANT RESEARCH SCHEDULE

Research report no.	Line No. 1					Line No. 2			
	Mode*	% Flow	Chemical	pH‡	Sludge+	% Flow§	Chemical	pH‡	Sludge+
1	P	50	L	6.0	N	50	L	7.0	N
2	P	50	L	5.0	N	50	L	7.0	N
3	P	50	LS	5.0	N	50	L	5.0	N
4	P	50	LS	6.0**	N	50	L	6.0**	N
5	P	50	LS	5.0	N	50	LS	6.0	N
6	P	50	LS	4.0	N	50	LS	5.0	N
7	P	50	LS	4.5	N	50	LS	5.0	N
8	S	100	L	5.0	N	100	L	7.0	N
8A	S	100	L	5.0	N	100	L	7.0	N#
9	S	100	L	4.0	N	100	L	7.0	N
10	S	100	L	4.0	N	100	L	6.0	N
11	S	100	L	4.0	R	100	L	7.0	R
12	S	100	L	4.0	R	100	L	6.0	R
13	P	50	L	6.0	R	50	L	7.0	R
14	P	75	L	6.0	R	25	L	7.0	R
15	P	75	L	6.0	N	25	L	7.0	N
16	S	50	LS	3.0-3.5	R	50	L	7.0	R
17	S	100	LS	3.0-3.5	R	100	L	7.0	R
18	S	100	LS	3.0-3.5	R	100	L	7.0	N
19	S	100	LS	3.0-3.5	N	100	L	7.0	N
20	P	50	LS	3.5	R	50	LS	4.0	R
21	P	75	LS	3.5	R	25	LS	4.0	R
22	S	100	LS	3.0-3.5	R	100	LS	6.0*	R
23	S	50	LS	3.5-4.0	R	50	LS	6.0*	R

* Mode; P=parallel; S=series; % Flow= percent of designed flow;
+ Sludge Recirculation; R= sludge recirculation; N= no sludge recirculation
‡ Optimum pH value # no aeration ** possible alternate - 2 times theoretical LS

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Table 4. MANUFACTURER'S ANALYSIS OF LIMESTONE DUST

Parameter	Percent min. comp.
CaO equiv.	52
MgO equiv.	2.4
$CaCO_3$	92.7
$MgCO_3$	5.9
Si	1.0
Al & Fe oxides	0.4

Screen size (mesh)	Limestone, % passing
- 70	98
- 100	95
- 200	75
- 325	65

LIME

The hydrated lime (R300) used in this study was obtained from Mississippi Lime Company, Alton, Illinois in order to obtain the smallest particle size commercially available.

Table 5 presents the manufacturer's representative analysis of rotary hydrated lime (R300) at a cost of $25.20 per ton ($22.86 per metric ton) or 1.26¢ per lb (2.77¢ per Kg).

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Table 5. MANUFACTURER'S ANALYSIS OF HYDRATED LIME

Parameter	Percent min. comp.
$Ca(OH)_2$	95.6
CaO equivalent	73.6
CaO total	74.2
$CaCO_3$	0.7
SiO_2	0.6
Al_3O_2	0.3
Fe_2O_3	0.1
MgO	0.5
$CaSO_4$	0.1
S	0.2
Free H_2O	0.5

Screen size	Hydrated lime, % passing
-200	99
-325	95.8

Element	Concentration (ppm by weight)
P	120
Mn	20
F	100
As	1
Cu	10
Pb	1
Ni	5
Se	10
Cd	0.6
Hg	0.05

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SECTION 2

CONCLUSIONS

Studies involving limestone and lime treatment of large volumes of acid mine drainage at high volume delivery have led to the following conclusions:

ECONOMICS

Acid mine drainage from the Will Scarlet Mine area can be neutralized to pH 7.0 with a combination of limestone and hydrated lime, or with hydrated lime alone.

Variations in treatment schemes indicated that the most economical mode of treatment in terms of operating cost (¢/1000 gals/1000 ppm acidity as $CaCO_3$), was achieved through combination treatment by utilizing limestone on line No. 1 with effluent pH 3.7 and lime on line No. 2 with final effluent pH 7.0. Sludge was recirculated on both treatment lines at an approximate rate of 200 GPM (757 l/min.) to each respective rapid mix vessel, representing 12-18% of the volume of plant influent.

Sludge recirculation had the overall effect of reducing cost of treatment when limestone was used as the neutralizing agent. In combination treatment, sludge recirculation was effective due to the recirculation of limestone, rather than lime sludge.

Detention time of treatment processes in excess of the theoretical minimum required contributed little in reducing the cost of treatment regardless of the treatment agent used.

CHEMISTRY OF TREATMENT

The removal of most metal cationic species was pH dependent. Thus, with increasing pH treatment levels, 85% or more removal of the following metals was observed at pH levels indicated:

Al (pH 5.0); Cr (pH 6.0); Cu (pH 6.5); Fe (pH 3.5); Mn (pH greater than 7.4); Ni (pH 7.6); Zn (pH 6.3). (Refer to Appendices - Part 11).

Increasing pH treatment levels further indicated the addition of certain cationic species. These cations included calcium, magnesium, lead and nickel in some cases with all treated effluents exhibiting near complete saturation levels of Calcium Sulfate ($CaSO_4 * 2H_2O$, gypsum).

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SLUDGE CHARACTERISTICS

Favorable settling behavior was exhibited by limestone-lime and lime treatment processes with the majority of resultant sludges settling in one hour. Higher solids content and more dense sludges resulted from limestone treatment of acid mine drainage at pH levels in excess of pH 4.5, than with lime treatment.

SECTION 3

RECOMMENDATIONS

1. Further studies should be conducted to determine adequate mixing of limestone in high volume delivery treatment of acid mine drainage. A tremendous solids buildup occurred in the aeration tanks at the Will Scarlet Water Treatment Plant when limestone was used as the neutralizing agent.
2. Highly alkaline industrial wastes should be considered as potential treatment agents in a search for more economical treatment costs.
3. Detailed study should be conducted to determine the effects of settling basin (Pit #10) effluent on the South Fork of the Saline River.
4. The settling basin (Pit #10) should be studied for possible industrial and recreational uses.
5. A detailed study should be conducted to determine the feasibility and economics of removal of purported trace toxic pollutants (i.e., Cd and Hg) in acid mine drainage.
6. A separate report should be prepared on operational aspects of treatment of high volume delivery of acid mine drainage.

SECTION 4

TREATMENT PLANT FACILITIES

PLANT LAYOUT

The Will Scarlet Water Treatment Plant is essentially a two-stage facility with both stages sized exactly the same. Basic units in the plant are illustrated schematically in Figure 3. The design hydraulic rate for the facility is 12,112 l/min (3,000 gpm). This flow rate will treat the anticipated runoff from the tributary drainage area in a maximum of 16 hours per day, 6 days per week. By initially operating the facility continuously and backfilling some of the pits with waste materials (gob) from the coal preparation operations, it was possible to work on some of the backlog of water accumulated throughout the area and thus lower the water table to a point where overflow water to the South Fork of the Saline River was no longer a threat.

DESCRIPTION OF EQUIPMENT

Raw Water Pumping Station

Two (2) 30.4 metric HP (30 HP), 6065 l/min (1600 gpm) Peerless Vertical Industrial pumps, each at 15.2 m (50 ft) of total dynamic head, are used for supplying raw water to the plant. The pump shaft, impeller, bowl, and suction bell are stainless steel. A 25.4-cm (10-in) length of schedule 40 pipe, coated with Macor 547 M is used as a discharge column.

12" Raw Water Line

The raw water line is Fibercast, BL 2025, corrosion resistant fiber glass, 9.14 kg/cm (130 psi) at 93°C (200°F).

Mixing Equipment (Rapid-Mix)

Mixing equipment consists of two (2) Chemineer Incorporated, Moduflex Turbine Agitators, Model MDJ 250-514. The shaft blades and stabilizer are stainless steel. Shaft speed is 125 rpm with a 253 metric HP (25 HP) turbine. Use of this equipment can result in a three minute detention time at 6056 l/min (1600 gpm) on each side of the facility.

Chemical Storage Bins

Chemicals are stored in bins purchased from the Butler Manufacturing

Company. The bins are constructed of 14-gauge galvanized steel with a diameter of 4.66 m (15 ft, 4-5/8 in) and a height of 15.5 m (51 ft) with a resulting total volume of 264.2 cu m (9,476 cu ft). Lime capacity of the bins is 50.8 metric tons (54 tons) while limestone capacity is 109 metric tons (120 tons). The chemical feed pipe is a 10.1-cm (4-in) diameter length of schedule 40 pipe.

Dust Collectors

Dust was collected using a Flex-Kleen Model 84BV16 dust collector with (16) 312-g (11-oz) Dacron felt bags. The Flex-Kleen collector has a capacity of 22.7 cu m/min (800 cu ft/min) air flow with a maximum air to cloth ratio of 0.03 cu m/min/sq m (6 cu ft/min/sq ft) with an exhaust fan rating of 229 cu m/min (810 cu ft/min) using a 20.3-cm (8-in) water gauge.

Vibrating Hopper

The Vibrating hopper is a product of Carmen Industries. It is a 2.4-m (8-ft) gyrated type, 2.03 metric HP (2 HP), 900 rpm, direct coupled eccentric weight unit. Its capacity is 1.87 cu m (66 cu ft) on a 60° slope, stroke adjustable, set on 0.064 cm (1/4 in). The hopper is mounted on 8 isolators (liquid-filled).

Chemical Feeder

The chemical feed equipment is a Belt Gravimeter Feeder, Model 37004 (rack and pinion gate hopper and feeder) manufactured by General Signal Corporation. The maximum belt speed of the feeder is 3.66 m/min (720 ft/hr) at a maximum feed rate of 6364 kg/hr (14,000 lbs/hr) at 29 kg/belt-m (19.4 lbs/belt-ft) delivery to the rapid mix vessel.

Screw Conveyor

A link belt, type C, shaft mounted conveyor with 30.48-cm (12-in) helical screw carries the combined flow to the aeration chamber. The screw conveyor is 3.66 m (12 ft) long and is turned by a motor rated at 5.05 metric HP (5 HP), 1800 rpm, reduced to 50 rpm.

Aeration Equipment

A Mining Equipment Company (Mixco) lightmix aerator, 10.1 metric HP (10 HP) is used to aerate the flow. The shaft and impeller are stainless steel. The upper blades are 152 cm (60 in) in diameter and the lower blades are 76.2 cm (30 in) in diameter. The blades turn at 56 rpm with a length of 304.8 cm (120 in) from the mounting base. Detention time in the aeration chamber is 27 minutes at a flow rate of 6056 l/min (1600 gpm).

Sludge Collection Equipment

Sludge is collected using American Positive Flight Conveyors by Keene Corporation with a dual drive, 0.51 metric HP (1/2 HP), 1800 rpm motor. The conveyors measure 10 m (32 ft, 10 1/2 in) center to center and 3.6 m (11 ft, 10 in) wide with a speed of .61 m/min (2 ft/min). The 8 flights on the conveyor are 5.1-cm x 15.2-cm (2-in x 6-in) redwood, 2 pivoted. Detention time is 20 minutes at a flow rate of 6056 l/min (1600 gpm).

Sludge Pumps

The sludge is pumped on each side by ITT Marlow, 5.05 metric HP (5 HP) varidrive motor, plunger pumps with positive displacement. The pumps have a 5 digit revolution counter and a maximum delivery of 1893 l/min (500 gpm) on each side.

Recirculation Pump

Water recirculation is by a Peerless Vertical Turbine with a 40.4 metric HP (40 HP), GE, variable speed control, electric motor. The turbine will pump 12,112 l/min (3200 gpm) at a head of 10.7 m (35 ft). The suction bell is stainless steel; the line shaft is carbon steel; and the bowl and impeller are cast iron with a 30.48-cm (12-in) discharge column of schedule 40 pipe. This equipment will allow recycling of the entire plant flow-through for certain operational sequences.

Construction Materials

Construction materials included 611.7 cu m (800 cu yd) of class A, 2.46 x 10-kg/sq m (3500-psi), 12.7-cm (5-in) slump concrete. Other construction materials were 72,574 kg (160,000 lb) of reinforcing steel and 1067 m (3500 ft) of 30.48-cm (12-in) concrete-filled shell piling.

Controls (Chemical)

Chemical control is accomplished by "SECO" SCR controller model 2159 potentiometers with a start-stop push button station in NEMA Izen oil dust-tight closures. The devices are 10-turn, 120-V, 60-cy, 1-pit, AC operation with tachometer feedback.

Controls (Flow)

Flow control is accomplished by a Fisher and Porter Magnetic Flowmeter, Model 10D1416A, size 20.3-cm (8-in) fiberglass-lined magmeter with 31655 electrodes and a 24-hour recorder.

Bristol Split-Flow Meter, Bubbler Type

The split-flow meter has a Model No. 0G685M-15-R260X transmitter, Model No. 2MiM500-R9A-Z38B 2-pen Metemeter Receiver, and Model No. 2MC500-238B electronic recorder.

Gates

Drain Gates are Warminster Fiberglass Company, Armco cast iron, fiberglass gates, guides, and troughs.

Portable Pump

The portable pump is a Gorman-Rupp, 5.1-cm (2-in) pump with a capacity of 378.5 l/min (100 gpm) at a head of 19.8 m (65 ft). This pump is to provide for washing and cleaning operations at the plant.

Air Compressor

The air compressor is an Ingersol-Rand, Model 253D5.

OPERATIONAL FEATURES AND PROCEDURES

Layout of the treatment plant and piping arrangements were devised for maximum flexibility of operational methods and techniques. The entire facility was designed to function as an effective research unit in which a number of variables were to be evaluated. The design was also undertaken so that further research programs, utilizing other treatment chemicals which showed promise, could be tested at high volume treatment levels. During research and nonresearch phases, Peabody Coal Company was able to utilize the plant on a production basis, thus reducing the volume of AMD backlog accumulated in the drainage basins.

Plant operational control was manual. Though equipped with an automatic pH monitoring system, its use was found to be impractical due to the rapid fouling of the pH probes. In-reactor pH was the single controlling factor in all treatment processes. Grab Samples were taken directly from treatment line effluents and analyzed in the plant laboratory. Values were then recorded, and adjustments made accordingly with belt-speeds of the chemical feeders for each treatment line. During each research stage, pH of the line effluent(s) was monitored on an hourly basis. Once the plant system had reached equilibrium, the desired pH level was maintained within 0.2 pH units.

EVALUATION OF PLANT OPERATION

Tremendous effort was made by all personnel concerned with the project to note and point out areas of operational difficulties. Due mainly to the large volume of AMD treated, the problems encountered were rarely of a small nature. Daily notes on plant operation were maintained by the researcher and field director while daily operating logs were recorded by union plant operators on each shift. Comments from these sources of information were then reflected in the Research Reports to the Field Director and further incorporated in the Monthly Progress Reports to the US Environmental Protection Agency.

Investigations were performed during non-research periods into such phenomena as chemical agent purity, "flushing" of raw water during plant operation, bench-scale studies of chemical reactivity, settle-ability of lime, limestone, and other potential treatment chemicals, and chemical treatment and removal of toxic substances to determine economic feasibility.

Many operational problems were encountered during the course of these studies and would best be addressed as a separate paper. Nonetheless, certain major problem areas are described in relation to specific structural plant components (Figure 3). A description of the major areas follows:

Component	Description of Operational Problem
Influent Channel	Inundation by siltation and coal fines from an adjacent slurry area.
Raw Water Pumps	Malfunction of brass/copper pump impellors; replacement with number 316SS bowl and impellor. Pump malfunction as a result of extreme corrosive effects of silts and coal fines.
Rapid Mix Vessel	Excessive gypsum buildup of 20-25 cm (8-10 in) thick on vessel walls and impellor shaft, resulting in damage to shaft from dislodged gypsum.
Chemical Storage	Initial plant start-up resulted in total failure of 4 liquid-filled isolators; 8 isolators were added. Frequent failure of "boot" for storage bin-feeder connector, resulting in total bin spillage.
Chemical Feeder System	Intermittent materials testing of the gravimetric feeders indicated a failure to meet an arbitrary 10 percent weight variance over several replicates. Though initially thought to be a problem with "dusting" when using hydrated lime, chemical testing of bulk lime loads indicated a chemical product far below manufacturer's specifications (94 percent as opposed to an actual 66 percent by weight as CaO).
Flow Measurement	Initial flow-measuring system failed due to clogging of air holes and electrical component failure. Solution was the purchase and installation of a magnetic flowmeter.
Aeration Vessel	Tremendous buildup of limestone fines during utilization. Required approximately 30-40 percent shutdown time for cleaning when using limestone.

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Component	Description of Operational Problem
Aeration Vessel cont.	Severe gypsum buildup on all vessel components (i.e. gates, walls and impellor). Use of grease was required.
Sludge Separation and Recirculation System	Severe gypsum scaling on all components (i.e. glides, walls, troughs and gates), to include intermittent plugging of recirculation system piping. Corrosive/abrasive effects of limestone fines on sludge pump graphite packing, when in operation, requiring continuous attention.
Recirculation Pump Station	Leakage of raw water from the flow-splitter into the recirculation pump station completely destroying pump.
Recirculation	Moderate buildup of gypsum in pump station during series flow treatment.
pH Monitoring Stations (Influent and Effluent)	Influent pH probes were rendered inoperable by moderate iron-fouling and total electrical failure of system due to caustic chemical dusts. Effluent probe was subject to extreme gypsum fouling requiring constant attention. Maximum operating time, prior to electrical system failure, was 3 hours.
Settling Basin Will Scarlet Mine Pit #10	Required effluent pH levels as designated in the research schedule resulted in poor impoundment water quality. Acid mine drainage runoff from Pit #10 spoil directly impacted impoundment water quality. Area has been totally reclaimed and has a good stand of vegetation. Extreme gypsum buildup on the Pit #10 outfall structure required explosives for clearing on several occasions.

SECTION 5

PROCEDURES

PHYSICAL MEASUREMENTS

Water flow rates were determined by continuously recording 24-hour split-flow weir chart recorders for each treatment line while total influent was measured by a Fisher-Porter Magnetic Flowmeter and continuous recorder. Chemical delivery was automatically recorded on a 5-digit counter for each chemical feeder and registered as the number of belt-feet of chemical added. Materials-testing of the chemical feeders was performed periodically to determine the percent efficiency of chemical feed at a pre-set counterpoise weight for each chemical agent [lime - 8.9 kg/belt-m (6 lb/belt-ft); limestone - 14.9 kg/belt-m (10 lb/belt-ft)]. Results of testing the chemical feeder delivery systems indicated that the delivery rate stayed within 5 percent of counterpoise weight settlings when feeding a chemical product of greater than 9 percent calcium oxide by weight.

CHEMICAL MEASUREMENTS

Plant influent and treated effluent(s) were sampled according to the schedule outlined in Table 6. Samples were taken manually at the plant outfall, and allowed to sit undisturbed until such time as a clear supernatant was prominent (approximately 1 hour). The supernatant was then drawn off for immediate analysis or sample-compositing and acid-preservation. At no time was a sample allowed to sit for more than twelve hours without analysis. The analyses are divided into two types: (1) Treatment Plant Laboratory Analyses, and (2) Central Laboratory Analyses for total metal concentrations.

Sulfate

Turbidimetric determination of sulfate concentration was performed on a 1:200 dilution of the sample after conditioning and addition of barium chloride (*Standard Methods*, 13th ed., pp. 334-335). Results were reported in ppm of sulfate.

Sludge Settling Behavior

A well-mixed 1,000-ml sample of treated effluent was placed in a 1,000-ml graduated cylinder. Sludge volume was recorded at 0-, 1-, 5-, 10-, 15-, 30-

45- and 60-minute intervals from initiation followed by records on 2-, 3-, 4-, 5-, 10-, and 24-hour intervals. Each reading was recorded as a percent of the initial sludge volume (100 percent). (Standard Methods, 13th ed., pp. 560).

TABLE 6. DAILY GRAB SAMPLING SCHEDULE OF PLANT INFLUENT AND TREATED EFFLUENTS

Sampling site	Type of sample(s)	Number of samples	Sampling frequency	Disposition of sample(s)
Plant influent	Composite	One	Four times daily	Collect & acidify 500 ml for metal analysis (Central Laboratory)
Plant influent	Grab	One	Four times daily	Immediate analysis
Line #1 effluent	Same	Same	Same	Same
Line #2 effluent	Same	Same	Same	Same

Solids Content

At the initiation of the sludge settling test, sludge samples were collected from the sludge pumps on both lines when operating under research conditions. Samples for solids content analysis were performed after 24 hours of settling time. The percent solids content was determined gravimetrically on a 5-ml aliquot of sludge, dried to constant weight at 103°C.

Temperature

Direct reading Fisher, mercury-filled, total immersion thermometers were used to report sample temperature in degrees centigrade.

pH

Potentiometric measurement of pH was performed using a Fisher Accumet pH meter, model 210, with standard glass pH electrodes.

Acidity

Potentiometric titration was accomplished to determine acidity, expressed as ppm of $CaCo_3$. A Fisher Accumet pH meter and Machlett Autoburet were utilized in the titration with 0.05 N NaOH and 3 percent hydrogen peroxide to endpoint pH 7.3 (Salotto, et.al., 1967). Results are reported in ppm of acidity expressed as $CaCO_3$ equivalent.

Alkalinity

Cold potentiometric titration, using a Fisher Accumet pH meter and Machlett Autoburet, was performed to an endpoint pH of 4.5 with 0.02 N HCL (Standard Methods, 12th ed., pp. 43-52). Results were reported in ppm of alkalinity expressed as $CaCO_3$ equivalent.

Specific Conductivity

A YSI Conductivity Meter, model 31, with a one centimeter probe was used to measure sample resistivity for comparison with a standard KCI solution for that instrument (Standard Methods, 13th ed., pp. 323-327). Results were reported in umhos/cm at 25°C.

Iron, Total

This parameter was determined directly by use of a Bausch & Lomb Spectronic model 20 and Hach Chemical Company reagents. Test results were compared to a standard curve for iron and reported in ppm total iron.

Iron, Ferrous

This test was performed as above and reported in ppm ferrous iron.

Metal Cations

Central Laboratory analyses were performed on composited, acid-preserved samples in the course of performing each research stage. Analytical work on the sample was performed on a Perkin-Elmer Model 403 Atomic Absorption Spectrophotometer after acid-digestion and preparation. Metal cations observed for the research period included copper, chromium, lead, zinc, iron, aluminum, manganese, nickel, calcium, and magnesium.

COMPUTER AND DATA PROCESSING

Computer and data processing services were utilized to determine and verify the rather large bulk of operational, cost, and analytical data generated during the research period. Operational data included sludge volumes, influent and treated effluent water volumes, recirculated sludge and plant influent ratios, and chemical agent weights added for each treatment unit.

With the introduction of chemical cost factors (¢/lb), treatment cost estimates were calculated in terms of ¢/1000 gal and ¢/1000 gal/1000 ppm acidity as $CaCO_3$. Detailed information for each research stage is contained in part A of the Appendix.

Data processing was primarily used in the manipulation of analytical data. This involved the calculation of percent removal (or percent addition) of specific parameters throughout a particular research scheme. Thus, through comparison of influent and effluent concentrations for each parameter, it was possible to graphically illustrate tendancies of specific metal concentrations throughout the research period. This information is incorporated as part B of the Appendix.

SECTION 6

RESULTS

Pursuant to the primary objectives performed according to the research schedule (Table 3), economics of treatment, chemistry of treatment, and sludge characteristics were observed during various research stages performed at the Will Scarlet Water Treatment Plant from March 1973 to February 1974. Each of the variables outlined in Table 11 was investigated and observed during limestone, lime, and limestone-lime (combination) treatment of acid mine drainage.

All studies on the variables were performed under continuous-flow conditions. Variation in influent water quality and raw water pump delivery throughout various research schemes accounted for specific differences in values.

LIMESTONE TREATMENT

Effect of pH

Titration curves were performed for limestone and lime on the Will Scarlet Plant influent on a number of occasions. Figure 4 represents typical reactivity curves for limestone and lime. Limestone's titration curve indicated that approximately 2.2 times as much limestone was required for treatment to pH level 6.0 than to pH 5.0. At no time during full scale plant operation or bench scale plant operation did the effluent pH achieve neutralization to pH 7.0 or higher with limestone.

Several continuous-flow tests were made at various pH levels. The flow rate approximated 30 minutes theoretical detention time with no sludge recirculation. Results of these tests (Table 7) indicate the effects of limestone treatment on effluent water quality.

Limestone treatment to pH 6.0 rather than pH 5.0 in continuous flow studies required 1.5 times as much limestone as compared to a factor of 2.2 from the titration curves. Further, only 1.9 times as much chemical was needed to achieve a treatment pH level of 5.0 rather than pH 4.5 (compared to 1.1 times in the titration curves).

Table 8 illustrates that optimum usage of limestone occurred in the pH range of 3.5 to 4.0; at higher pH levels, the usage was markedly increased.

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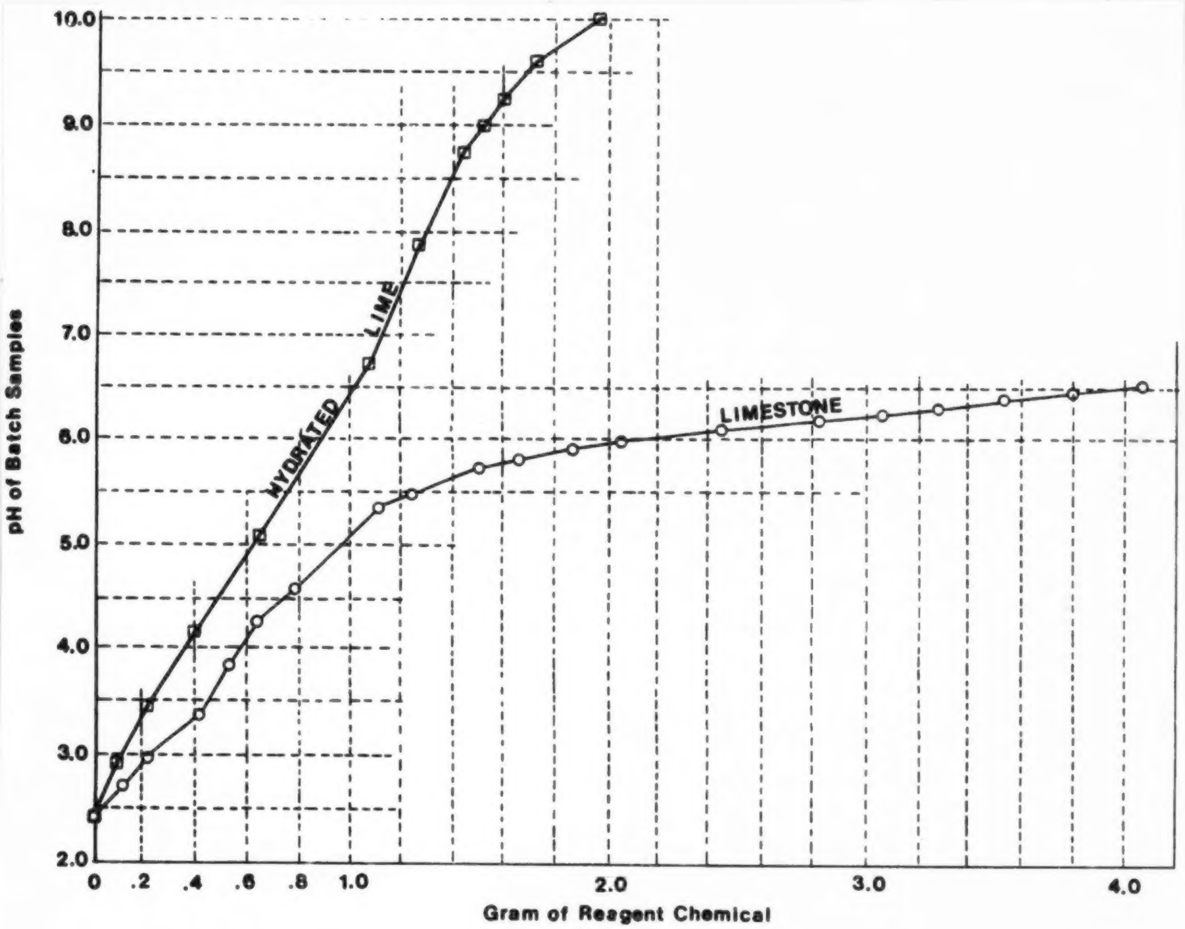

Figure 4 Reactivity curves of limestone and lime.

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TABLE 7. EFFECTS OF pH ON EFFLUENT QUALITY AND LIMESTONE TREATMENT REQUIREMENTS

Report No.	Effluent pH	Limestone Usage (lb/1000 gal)*	Total Iron (mg/l)	Effluent Quality Acidity (mg/l as $CACO_3$)	Alkalinity (mg/l as $CACO_3$)
3	3.4	9.0	57	1700	0
4	4.1	19.7	3.3	844	0
5	4.5	29.0	1.7	3.4	1.3
5	4.7	28.4	3.9	259	1.0
6	5.2	51.9	1.8	.20	28

*To convert lb/1000 gal to kg/cu m, multiply by 0.120.

TABLE 8. UNIT EFFICIENCY OF LIMESTONE TREATMENT AT VARIOUS PH LEVELS

Report no.	Effluent pH	Efficiency (%)*
3	3.4	73
4	4.1	84
5	4.5	47
6	5.2	55

*Percent Efficiency =

$$\frac{\text{acidity removed + alkalinity added}}{\text{(wt. of neutralizing chemical as mg/l } CaCO_3\text{) X purity}} \text{ X } 100$$

Effects of Detention Time

The effects of detention time were evaluated by plant operation in parallel flow (50 percent of influent to each treatment line), non-parallel flow (75 percent influent to line No. 1 and 25 percent to line No. 2) and series or two-stage treatment at 50 percent or 100 percent of design capacity (Table 9). As noted by Wilmoth (1974), detention times of 20 to 30 minutes appeared to be adequate for limestone reactivity.

TABLE 9. THEORETICAL DETENTION TIME (MINUTES)

Flow(gpm)*	Reactor	Aerator	Sludge System+	Total
800	6	54	40	100
1600	3	27	20	50
2400	2	18	14	34
3200	1.5	13.5	10	25

* multiply gallons per minute by 0.0631 to obtain liters/sec
+ utilized only during sludge recirculation periods

Reduction in limestone usage was less than 3 percent with increasing detention time from 25 to 75 minutes. However, plant treatment efficiency was highest with plant operation in a theoretical detention time range of 12.5 to 37.5 minutes.

Effects of Sludge Recirculation

The effects of recirculation of limestone sludges were evaluated relative to a number of factors including treatment efficiency, solids content and economics of treatment. Table 8 indicates that optimum treatment efficiency occurred between pH levels 3.4 and 4.1. To further optimize the efficiency and observe the effects of sludge recirculation, operational data were evaluated (Table 10). Lowest unit cost and highest treatment efficiency was again observed between treatment pH levels 3.3 and 4.1 with sludge recirculation. Further, Table 10 illustrates the combined effect of detention time and sludge recirculation (primarily the latter) with respect to economics of treatment at various pH levels.

Two-stage treatment with limestone exhibited little or no advantage in increasing the efficiency of treatment as compared to single stage treatment. However, unit treatment costs were lower with sludge recirculation (as opposed to no sludge recirculation).

As to the characteristics of resultant sludges, limestone treatment to progressively higher pH levels exhibited correspondingly higher final (24-hour) sludge volumes and solids content without sludge recirculation. However, as noted in Table 11, the generation of minimum sludge volumes at lowest unit costs with a maximumization of sludge solids content and treatment efficiency was exhibited at treatment levels pH 3.3 to 4.0. Again, initial limestone treatment of the plant influent appeared to be most beneficial to the overall treatment process.

LIME TREATMENT

Effect of pH

As shown on Figure 4 (titration curves for limestone and lime), 1.5 times as much lime was required for treatment to pH level 6.0 than to pH 5.0, while only 1.8 times as much lime was required to achieve neutralization at pH 7.0 than to effect a treatment pH level of pH 5.0. During single-stage (parallel flow) and two-stage (series flow and combination) treatment, the effluent was treated to pH 7.0 or higher.

Continuous-flow testing utilizing hydrated lime was performed at a number of pH levels. Extreme fluctuations in lime requirements were observed and specifically reflected changes in plant influent water quality. Table 11 illustrates the water quality of selected intermediate and final lime-treated effluents.

TABLE 10. CHARACTERISTICS OF LIMESTONE SLUDGES

Test No.	Effluent pH	Ratio Sludge* Influents	(%) Sludge Volume+	(%) Solids Content++	Cost§	% Efficiency
Parallel flow, no sludge recirculation:						
5A	4.7	0	5	6.4	15.6	47.1
5B	5.8	0	5	6.7		
6A	4.1	0	2.5	5.6	11.7	54.7
6B	5.2	0	5	6.2		
7A	4.5	0	4	5.9	11.9	46.1
7B	5.2	0	5	6.5		
Parallel flow, with sludge recirculation:						
20A	3.3	0.10	1	6.5	3.7	72.1
20B	3.9	0.13	3	6.8		
21A	3.3	0.09	1	6.4	3.7	74.0
21B	4.0	0.18	2	7.1		
Series flow, with sludge recirculation:						
22A	4.0	0.10	2	13.2	6.9	54.4
22B	6.1	0.12	3	27.3		
23A	3.3	0.11	1	4.7	7.2	50.6
23B	6.3	0.10	4	8.3		

* Ratio of total sludge recirculated to total plant influent.

+ Resultant sludge volume after 24-hr settling time.

++ Solids content as a percent, determined gravimetrically.

§ Cost as ¢/1000 gal/1000 ppm acidity as $CaCO_3$.

TABLE 11. EFFECT OF pH ON EFFLUENT QUALITY AND LIME REQUIREMENTS

Test no.	Effluent pH	Lime requirement (lb/1000 gal)[+]	Effluent quality		
			Total Fe (mg/l)	Acidity (mg/l as CaCO3)	Alkalinity (mg/l as CaCO3)
9	(3.8)*	(10.9)	(18)	(1300)	(0)
11	(4.0)	(13.0)	(10)	(1200)	(0)
2	4.9	11.4	4.9	120	1.6
14	6.0	21.6	2.3	37	5.0
13	7.1	29.8	2.0	17	8.2

*Parentheses denote effluents from treatment line No. 1.

[+] Multiply lb/1000 gal by 0.120 to obtain kg/cu m.

It is of particular interest to note that lime treatment in either single-stage or two-stage treatment flow did not produce an effluent with net alkalinity.

Table 12 indicates that a maximization of treatment efficiency with a minimization of resultant cost was exhibited by series (two-stage) treatment to a pH range of pH 6.0 to 7.0, with or without sludge recirculation. Single stage treatment exhibited the highest costs.

Effects of Detention Time and Sludge Recirculation

Increasing the theoretical detention time did effect an increase in treatment efficiency, but with no significant change in cost of treatment for single-stage schemes. Increased efficiency and minimal costs were primarily observed during series (two-stage) treatment, with sludge recirculation, to pH treatment levels 6.0 to 7.0.

Resultant sludges exhibited generally higher solids content and final volumes with increased detention time and sludge recirculation (Table 13). Maximum treatment efficiency at lowest unit cost produced sludges with the highest solids content and lowest sludge volumes after the 24-hr test period (Figure 5). This was the result of series (two-stage) treatment to treatment pH level 6.0 to 7.0, regardless of sludge recirculation.

LIMESTONE VS. LIME

Two parallel continuous-flow studies were made using limestone on Line No. 1 and lime on Line No. 2 to treatment levels of pH 5.0 and 6.0, respectively. Parallel flow treatment with no sludge recirculation allowed for simultaneous treatment of the same plant influent in order to observe differences in operational data and effluent water quality.

Table 14 is a summarization of data generated during the aforementioned treatment schemes. Limestone treatment exhibits several advantages over lime treatment: (1) lower sludge volumes; 4 vs 13 percent and 3.5 vs 19 percent;

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TABLE 12. TREATMENT EFFICIENCY USING LIME

Test No.	Effluent pH	Treatment efficiency (%)*	Cost+	Theoretical detention time (min.)
Parallel flow, no sludge recirculation:				
1A	5.8	73	8.4	30
1B	6.8	--	-	30
2A	4.9	77	8.8	30
2B	7.1	--	-	30
15A	6.1	79	11.5	15
15B	7.1	--	-	45
Parallel flow, with sludge recirculation:				
13A	6.1	80	5.6	30
13B	7.1	--	-	30
14A	6.0	86	6.4	15
14B	6.9	--	-	45
Series flow, no sludge recirculation:				
10	5.8	86	6.1	50
9	6.6	88	6.1	50
Series flow, with sludge recirculation:				
11	7.0	75	7.8	50
12	6.2	93	6.7	50

* Refer to Page 28 for definition.

+ Cost as ¢/1000 gal/1000 ppm acidity as $CaCO_3$.

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TABLE 13. CHARACTERISTICS OF HYDRATED LIME SLUDGES

Test No.	Effluent pH	Ratio* sludge/influent	Sludge+ Volume (%)	Solids Content (%)
Without sludge recirculation:				
2A	4.9	0	14	1.9
1A	5.8	0	13	1.7
10	5.8	0	18	4.8
15A	6.1	0	25	4.8
9	6.6	0	13	5.0
1B	6.8	0	13	1.9
15B	7.1	0	20	6.7
2B	7.1	0	14	1.7
With sludge recirculation:				
14A	6.0	0.09	21	5.3
13A	6.1	0.10	25	4.4
12	6.2	0.11	15	5.9
14B	6.9	0.16	18	6.0
11	7.0	0.11	13	4.2
13B	7.1	0.13	25	4.8

* Ratio of sludge recirculated to plant influent volume.
+ Sludge parameters determined after 24-hr. settling time.

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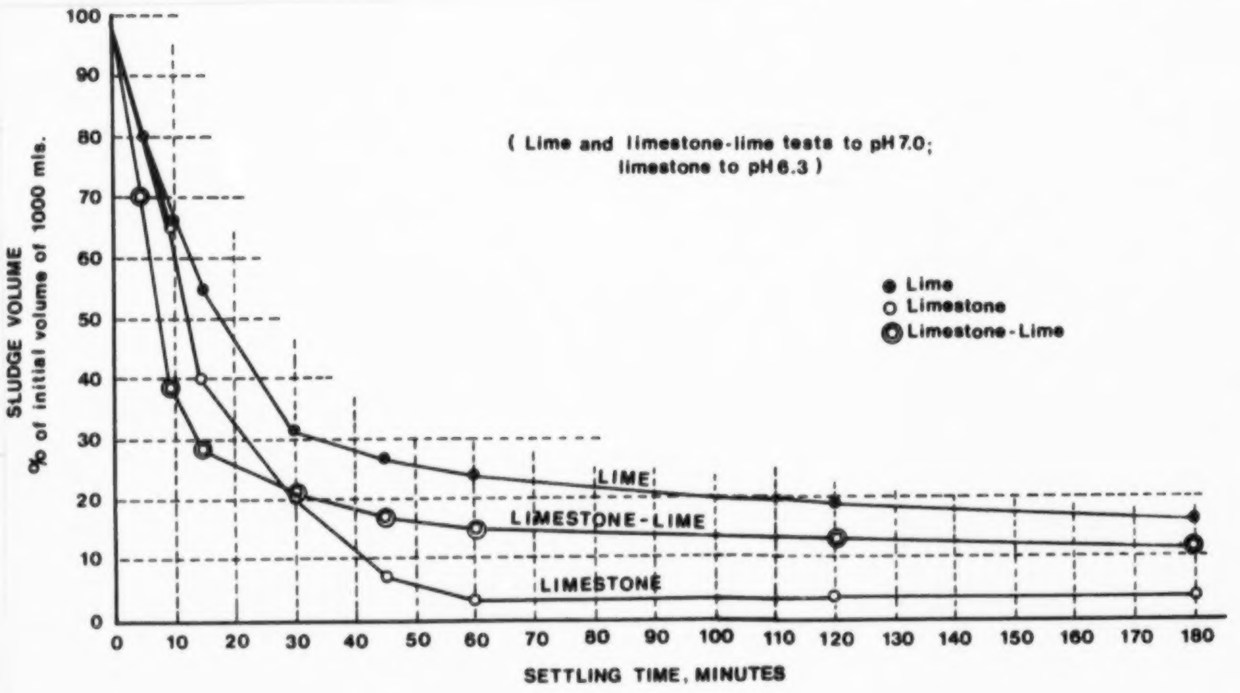

Figure 5 Sludge settling behavior
(settling time vs percent of initial Volume)

TABLE 14. COMPARISON OF LIMESTONE AND LIME TREATMENT

Item	Influent 3	Effluents 3A	Effluents 3B	Influent 4	Effluents 4A	Effluents 4B
Chemical	-	limestone	lime	-	limestone	lime
pH	2.8	5.0	5.1	2.7	5.6	6.0
Treatment requirement (lbs./1000 gal)	-	23.5	15.8	-	23.7	16.1
Chemical cost (¢/1000 gal/1000 ppm acidity)	-	5.4	9.5	-	5.0	9.2
Treatment efficiency (%)	-	65	82	-	77	92
Total iron (mg/l)	300	3.0	1.1	309	2.0	2.2
Acidity (mg/l)	2000	220	74	2200	93	19
Alkalinity (mg/l)	0	23	2.9	0	48	7.5
Sludge volume (%) (after 24-hr)	-	4	13	-	3.5	19
Sludge solids content (%) (after 24-hr)	-	5.6	1.8	-	6.5	1.9

(2) higher solids content in the sludges; 5.6 vs 1.8 percent and 6.5 vs 1.9 percent; (3) lower chemical treatment costs and (4) greater ease of materials handling. However, limestone's inefficient reactivity results in inability to attain pH levels greater than 6.5 and in the deposition of large quantities of limestone "fines" in aeration tanks and effluent structures and channels. The lower efficiency of limestone treatment can only indicate that much of this chemical is unreacted at the plant outfall and, in essence, wasted into the sludge settling basin.

COMBINATION LIMESTONE-LIME TREATMENT

In an effort to combine the advantages of limestone and lime treatment, a series of combination (two-stage) limestone-lime treatment processes were performed. Limestone's high reactivity and efficiency with low treatment costs at lower pH ranges (pH 3.4 to 4.1) were utilized in the first stage of treatment with recirculation of resultant sludges. Lime, though more expensive, proved to be highly reactive, efficient, and capable of effecting desirable results in the pH range 6.0 to 7.0. Second stage lime treatment was utilized to achieve neutralization of the final treated effluent at pH 7.0, "polishing" the intermediate limestone effluent.

Investigations of combination limestone-lime treatment involved operation of the treatment plant in series (two-stage) flow as follows:

TABLE 15. PLANT OPERATIONAL VARIABLES FOR COMBINATION LIMESTONE-LIME TREATMENT

Item	Line 1	Line 2
Treatment pH	3.5 - 4.0	7.0
Chemical	limestone	lime
% Flow	50 or 100	50 or 100
Sludge recirculation	yes or no	yes or no

Variables for investigation included detention time (50 percent flow - one raw water pump or 100 percent flow - both raw water pumps) and sludge recirculation. In all combination tests (Nos. 16, 17, 18, and 19) limestone was utilized for first stage treatment to a pH range of 3.5 to 4.0, and lime treatment of the intermediate limestone effluent was accomplished to approximately pH 7.0. With the exception of Research Stage No. 16 at 50 percent influent capacity, 5.49 cu m/min (1450 gpm), all other research stages involved a 100 percent influent delivery at approximately 10.97 cu m/min (2900 gpm) with a theoretical detention time of approximately 50 minutes. Results of the tests are shown in Table 16.

TABLE 16. COMBINATION LIMESTONE-LIME TREATMENT COST AND EFFICIENCY

Report no	Intermediate pH (limestone)	Limestone requirement (lb/1000 gal)	Final pH (lime)	Lime requirement (lb/1000 gal)	Operating cost*	Efficiency+
16	3.7	4.5	7.8	6.3	13.1	89
17	3.7	4.5	7.1	5.0	8.9	94
18	3.5	4.2	7.2	8.3	8.5	87
19	3.4	9.0	7.3	12.4	8.6	84

* ¢/1000/ppm acidity
+ See page 28 for definition.

Chemical costs were an important aspect for consideration. Research Stage No. 18 exhibited the most economical scheme of treatment with a unit chemical cost of 1.8 cents/1000 1/1000 ppm acidity (6/9 cents/1000 gal/1000 ppm acidity) and a total unit operating cost of 2.2 cents/1000 1/1000 ppm acidity (8.5 cents/1000 gal/1000 ppm acidity). However, maximum efficiency of treatment for the entire project was exhibited by Research Stage No. 17 at an operating cost of 2.4 cents/1000 1/1000 ppm acidity (8.9 cents/1000 gal/1000 ppm acidity) as $CaCO_3$. Small variations in the unit costs of these two treatment modes are due in part to differences in the quality of influent water and the total volume of water treated.

EFFECT OF DETENTION TIME AND SLUDGE RECIRCULATION

Results of plant operation indicated that increasing sludge recirculation and theoretical detention time had little to no effect in reducing the overall cost of treatment. However, the recirculation of limestone and limestone-lime sludges did increase the efficiency of treatment. As noted in Table 17, more dense sludges with lower final sludge volumes were observed during Research Stage No. 17.

Sludge settling rates were difficult to determine for limestone sludges at treatment pH levels less than pH 5.0. However, a distinct interface between settling sludge and supernatant was present for lime and limestone-lime effluents and limestone effluents of pH 5.0 or greater. It would have been beneficial to note sludge buildup, supernatant turbidity and sludge settling behavior, however, only sludge settling behavior was considered throughout this research project. Water treated with lime clarified most rapidly, followed closely by limestone-lime treatment (Figure 5). All three supernatants obtained similar clarity at the end of one hour with further sludge compaction completed by the end of 3 hours settling time.

Sludge produced by lime was the least dense of the three and compacted gradually. Limestone and limestone-lime treatment produced significantly smaller volumes of sludge than did lime treatment. After 2 hours of settling time, lime sludge occupied approximately 18 percent of its original volume while limestone sludge settled to less than 5 percent of its original volume.

TABLE 17. SLUDGE CHARACTERISTICS COMBINATION (LIMESTONE-LIME) TREATED EFFLUENTS

Report no	Effluent pH	Ratio sludge/ influent*	Sludge+ volume	Sludge content‡	Efficiency§
16	7.8	.21	8.0	2.7	89
17	7.1	.13	8.0	5.2	94
18	7.2	.06	14.0	1.6	87
19	7.3	0	15.0	2.6	84

* (a) Ratio of sludge recirculated to plant influent.

+ (b) Percent of initial sludge volume after 24 hr settling time.

‡ (c) Percent solids content after 24 hr settling time.

§ (d) See page 34 for definition.

‡ (e) Sludge recirculated on Treatment Line No. 1 only.

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1. Koehrsen, L. G., and A. F. Grandt. Mine Drainage Control - Design for Reclamation and Neutralization. In: Proceedings of the 25th Annual Purdue Industrial Wastes Conference, West Lafayette, Indiana, 1970. pp. 465-471.

2. Stanley Consultants, Inc. Report on Acid-Mine Drainage Neutralization for Will Scarlet Mine. Project No. 4335-20. Muscatine, Iowa, 1968. 43 pp.

3. American Public Health Association. Standard Methods for the Examination of Water and Wastewater. 13th ed. Washington, D.C., 1975. 874 pp.

4. Salotto, B. V., E. F. Barth, M. B. Ettinger, and W. E. Tolliver. Determination of Mine Waste Acidity. U.S. Department of the Interior, FWPCA, Cincinnati, Ohio, 1967. 26 pp.

5. Wilmoth, R. C., and R. B. Scott. Limestone and Limestone-Lime Neutralization of Acid Mine Drainage. EPA-670/2-74-051, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1974. 92 pp.

APPENDIX

PART A

RESEARCH REPORTS: WILL SCARLET WATER TREATMENT PLANT

WILL SCARLET WATER TREATMENT PLANT RESEARCH REPORT NO.

DATE April 18, 1973

I. DESCRIPTION OF RESEARCH STAGE

A. According to the research schedule, hydrated lime was used as the neutralizing reagent on both lines at a counterpoise weight of six pounds of lime per belt-foot. There was no sludge recirculation and the flow pattern was parallel (50/50). An effort was made to maintain line #1 at pH 6.0 and line #2 at pH 7.0.

B. For the research period, March 26-30, 1973 (120 hours of operation) the following summary of treatment is submitted:

TABLE I TREATMENT DISCHARGE VOLUMES*

Units	Total Water Influent	Line I Water Influent	Line 2 Water Influent
Gallons	16,200,000	9,720,000	6,480,000
Liters	61,362,360	36,817,416	24,544,944

*pH desired: Line I, 6.0; line 2, 7.0; Actual pH: Line I, 5.8; Line 2, 6.8; influent, 2.7

TABLE 2 TREATMENT REQUIREMENT SUMMARY

Item	Line I	Line 2
Alkalinity added (mg/l as $CaCO_3$)	5.00	8.00
Sludge volume (% of initial volume after 24 hours)	13.00	13.00
Treatment required (lb chemical/1000 gal influent)	9.64	18.49

TABLE 3 TREATMENT COST SUMMARY

Line	Cost Unit*	Total Weight+	Water Influent#	¢/vol§	¢/vol/ppm‡‡
1	1.26	93,708	9,720,000	12.1	4.3
2	1.26	119,832	6,480,000	23.3	8.3
Subtotal:	--	213,540	16,200,000	--	-
Total (chemical only):		---	---	16.6	5.9
Total (operating):		---	---	23.5	8.4

* ¢/lb of chemical

+ lb of chemical

# Gal of water treated

§ Cost, ¢/1000 gal of plant influent

‡‡ Cost, ¢/1000 gal of plant influent/1000 ppm acidity as $CaCO_3$ (b.p. to pH 8.3)

2. RESULTS OF TREATMENT PLANT ANALYSIS

Refer to Table 4

3. RESULTS OF METAL ANALYSIS FROM THE CENTRAL LABORATORY

Refer to Table 5

4. PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

Refer to Table 6

5. PROPERTIES OF PLANT SLUDGE

A. Sludge settling behavior

Refer to Figure 1

B. Solids content (%) of sludges

Line	%
Line 1	1.72
Line 2	1.91

TABLE 4 RESULTS OF TREATMENT PLANT ANALYSES

Parameter	Plant Influent			Line 1			Line 2		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Temperature (C)	11.8	17.5	13.3	11.8	16.2	13.6	11.5	17.2	13.8
pH	2.77	2.81	2.71	5.1	6.8	5.8	6.3	7.3	6.8
Acidity, b.p. to pH 8.3*	2800	2900	2800	17	140	56	13	38	24
Acidity, cold to 7.3, H_2O_2*	2500	2600	2500	12	47	11	0	20	10
Alkalinity*	0	0	0	2	10	5	6	13	8
Specific conductance+	3300	5100	4600	3600	5200	4600	4000	5400	4800
Iron, ferrous, ppm	0	0.1	0.1	0.1	0.1	0.1	0	0.1	0.1
Iron, ferric, ppm	145	195	167	0	0.1	0.1	0	1.10	0.59
Sulfate, SO_4 ppm	3900	4100	4000	3500	3700	3600	3500	3600	3600

* ppm as $CaCO_3$

+ umhos/cm at 25C

TABLE 5 METAL ANALYSIS* (A.A. SPECTROPHOTOMETRY FROM CENTRAL LAB.)

Collection site	pH	Cu	Cr	Pb	Mn	Fe	Zn	Al	Ni	Mg	Ca
☐ Plant influent	2.75	0.20	0.09	0.12	63.0	380.0	7.00	230.0	2.99	556	241
☐ Aeration tank #1	6.0	0.05	0.05	0.26	47.0	2.32	3.85	3.60	2.13	295	1,188
☐ Aeration tank #2	7.0	0.03	0.04	0.30	32.0	3.27	0.22	2.30	0.91	286	1,196

*Results in mg/l; pH in standard units

TABLE 6 PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

PARAMETER	Percent removal/addition Line 1	 Line 2
Treatment pH	4.8	6.8
Acidity	99.60-	99.70-
Conductivity	.00-	4.30+
Sulfate	10.00	10.00
Copper	75.00	85.00
Chromium	44.50	55.60
Lead	116.60+	150.00+
Manganese	25.40-	49.30-
Iron ABS	99.40-	99.20-
Zinc	45.00	96.90-
Aluminum	98.50-	99.00-
Nickel	28.80-	69.60-
Magnesium	47.00-	48.60-
Calcium	392.90+	396.20+

* - indicates percent removal
+ + indicates percent addition

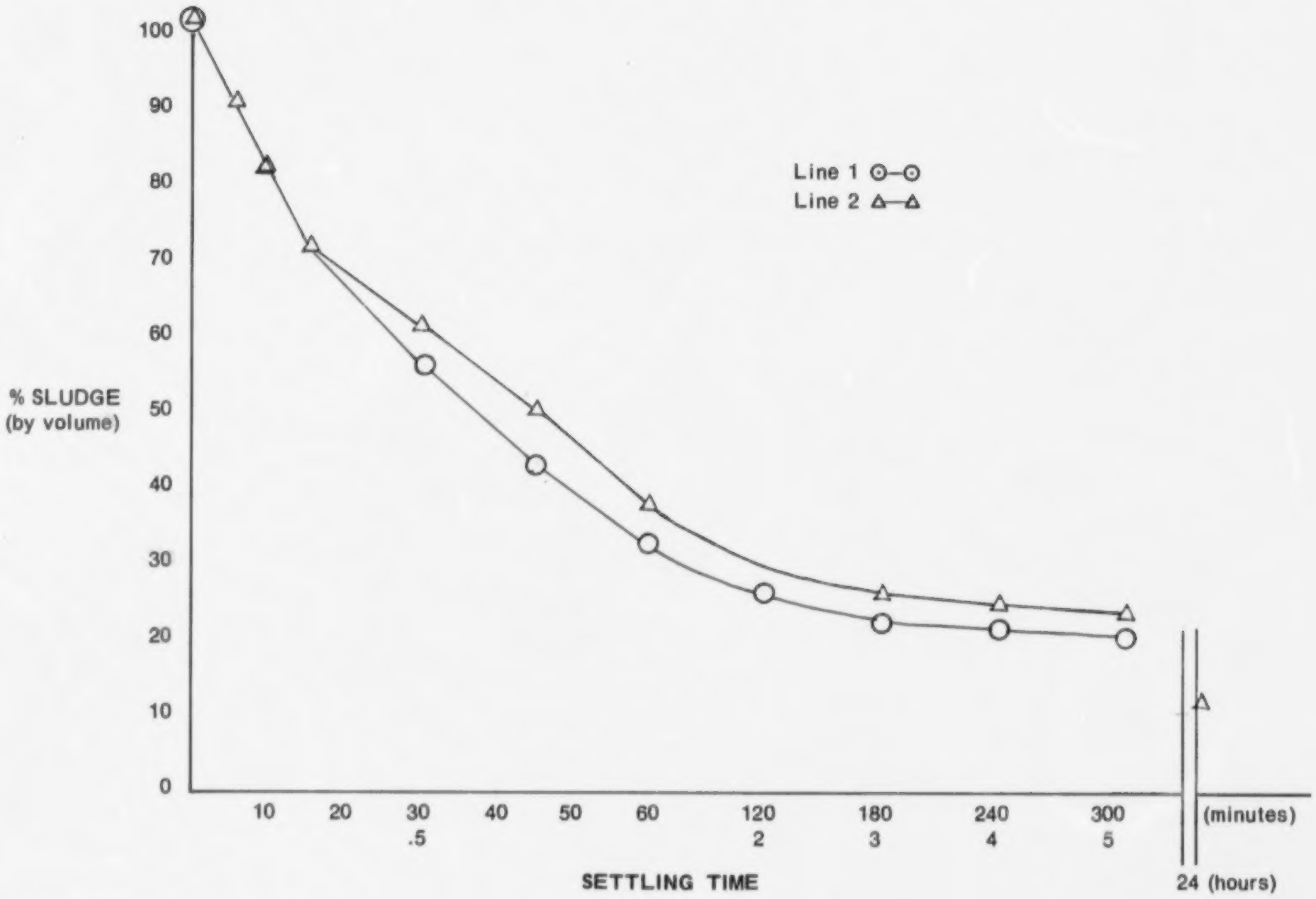


Figure 1.
SLUDGE SETTLING BEHAVIOR

WILL SCARLET WATER TREATMENT PLANT RESEARCH REPORT NO. 2

DATE May 7, 1973

I. DESCRIPTION OF RESEARCH STAGE

A. According to the research schedule, hydrated lime was used as the neutralizing reagent on both lines at a counterpoise weight of six pounds of lime per belt-foot. There was no sludge recirculation and the flow pattern was parallel (50/50). An effort was made to maintain line #1 at pH 5.0 and line #2 at pH 7.0.

B. For the research period, April 9-13, 1973 (120 hours of operation) the following summary of treatment is submitted:

TABLE 1 TREATMENT DISCHARGE VOLUMES*

Units	Total Water Influent	Line 1 Water Influent	Line 2 Water Influent
Gallons	16,200,000	9,720,000	6,480,000
Liters	61,362,360	36,817,416	24,544,944

*pH desired: Line 1, 5.0; line 2, 7.0; Actual pH: Line 1, 4.9;
Line 2, 7.1;
influent pH, 2.8

TABLE 2 TREATMENT REQUIREMENT SUMMARY

Item	Line 1	Line 2
Alkalinity added (mg/l as $CaCO_3$)	2.00	10.00
Sludge volume (% of initial volume after 24 hours)	14.00	14.00
Treatment required (lb chemical/1000 gal influent)	11.36	20.16

TABLE 3 TREATMENT COST SUMMARY

Line	Cost Unit*	Total Weight+	Water Influent#	¢/vol§	¢/vol/ppm‡‡
1	1.26	110,502	9,720,000	14.3	4.9
2	1.26	130,680	6,480,000	25.4	8.8
Subtotal:	--	241,182	16,200,000	--	-
Total (chemical only):		---	---	18.8	6.5
Total (operating):		---	---	25.6	8.8

* ¢/lb of chemical

+ lb of chemical

# Gal of water treated

§ Cost, ¢/1000 gal of plant influent

‡‡ Cost, ¢/1000 gal of plant influent/1000 ppm acidity as $CaCO_3$ (b.p. to pH 8.3)

2. RESULTS OF TREATMENT PLANT ANALYSIS

Refer to Table 4

3. RESULTS OF METAL ANALYSIS FROM THE CENTRAL LABORATORY

Refer to Table 5

4. PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

Refer to Table 6

5. PROPERTIES OF PLANT SLUDGE

A. Sludge settling behavior

Refer to Figure 1

B. Solids content (%) of sludges

Line 1	1.88
Line 2	1.68

TABLE 4 RESULTS OF TREATMENT PLANT ANALYSES

Parameter	Plant Influent			Line 1			Line 2		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Temperature (C)	9.2	12.2	10.5	9.2	13.4	10.8	9.0	13.8	10.8
pH	2.7	2.91	2.8	4.6	5.1	4.6	6.8	7.1	7.1
Acidity, b.p. to pH 8.3*	2700	3100	2900	91	450	230	20	45	31
Acidity, cold to 7.3, H_2O_2*	2500	2700	2600	34	280	120	5.6	11	7.6
Alkalinity*	0	0	0	-5.0	6.3	1.6	8.0	14	10
Specific conductance+	4900	5300	5100	4900	5300	5100	4800	5700	5200
Iron, ferrous, ppm	0	0.60	0.1	0	0.59	0.16	0	0.52	0.11
Iron, ferric, ppm	169	390	312	1.2	5.3	2.8	0.2	3.3	2.4
Sulfate, SO_4 ppm	3300	4500	4000	2900	3500	3100	2900	4200	3500

* ppm as $CaCO_3$

+ umhos/cm at 25C

TABLE 5 METAL ANALYSIS* (A.A. SPECTROPHOTOMETRY FROM CENTRAL LAB.)

Collection site	pH	Cu	Cr	Pb	Mn	Fe	Zn	Al	Ni	Mg	Ca
☐ Plant influent	2.80	0.11	0.12	0.17	66.0	400	10.4	205	2.44	75.0	195
☐ Aeration tank #1	4.88	0.05	0.07	0.16	56.5	4.94	10.0	35.0	2.36	125	1,050
☐ Aeration tank #2	7.13	0.03	0.07	0.13	33.0	1.94	0.03	1.80	0.59	135	900

*Results in mg/l; pH in standard units

TABLE 6 PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

PARAMETER	Percent removal/addition	
	Line 1	Line 2
Treatment pH	4.9	7.1
Acidity	95.40	99.70
Conductivity	.00-	1.90+
Sulfate	21.00-	12.20-
Copper	54.60-	72.80-
Chromium	41.70-	41.70-
Lead	5.90-	23.60-
Manganese	14.40-	50.00-
Iron ABS	98.80-	99.60-
Zinc	3.90-	99.80-
Aluminum	83.00-	99.20-
Nickel	3.30-	75.90-
Magnesium	66.60+	80.00+
Calcium	438.40+	361.50+

* - indicates percent removal
+ + indicates percent addition

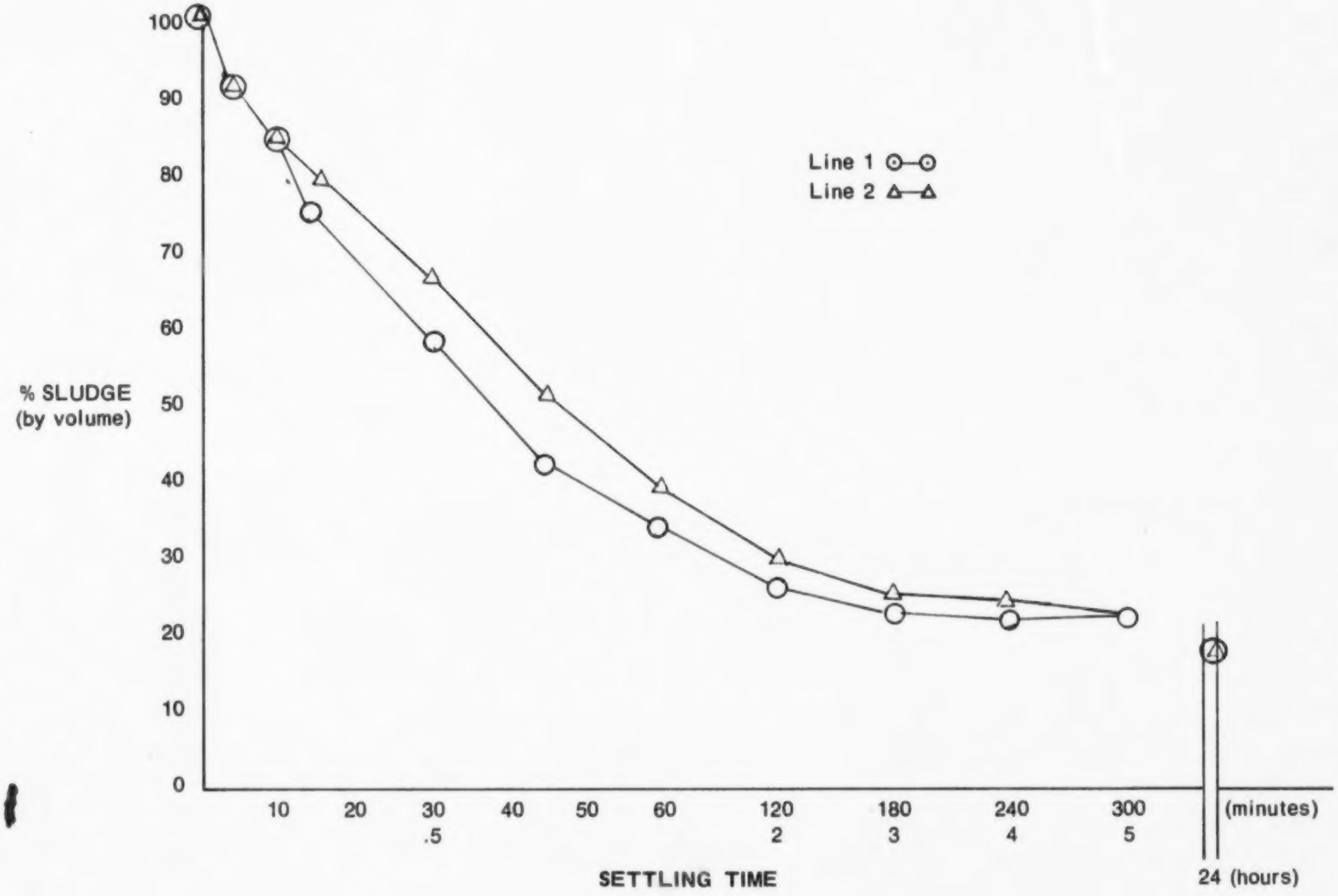


Figure 1.
SLUDGE SETTLING BEHAVIOR

WILL SCARLET WATER TREATMENT PLANT RESEARCH REPORT NO. 3

DATE May 29, 1973

I. DESCRIPTION OF RESEARCH STAGE

A. According to the research schedule, hydrated lime was used as the neutralizing reagent on both lines at a counterpoise weight of six pounds of lime per belt-foot. There was no sludge recirculation and the flow pattern was parallel (50/50). An effort was made to maintain line #1 at pH 5.0 and line #2 at pH 5.0.

B. For the research period, April 30, 1973 to May 4, 1973, (119.5 hours of operation) the following summary of treatment is submitted:

TABLE 1 TREATMENT DISCHARGE VOLUMES*

Units	Total Water Influent	Line 1 Water Influent	Line 2 Water Influent
Gallons	14,985,300	8,962,500	6,022,800
Liters	56,761,319	33,948,157	22,813,161

*pH desired: Line 1, 5.0; line 2, 5.0; Desired pH: Line 1, 5.0; Line 2, 5.1; influent, 2.8

TABLE 2 TREATMENT REQUIREMENT SUMMARY

Item	Line 1	Line 2
Alkalinity added (mg/l as $CaCO_3$)	23.00	3.00
Sludge volume (% of initial volume after 24 hours)	4.00	13.00
Treatment required (lb chemical/1000 gal influent)	23.54	15.82

TABLE 3 TREATMENT COST SUMMARY

Line	Cost Unit*	Total Weight+	Water Influent#	¢/vol§	¢/vol/ppm‡‡
1	0.46	211,040	8,962,500	10.8	4.5
2	1.26	95,286	6,022,800	19.9	8.3
Subtotal:	--	306,326	14,985,300	--	-
Total (chemical only):		---	---	14.5	6.0
Total (operating):		---	---	21.7	9.1

* ¢/lb of chemical

+ lb of chemical

# Gal of water treated

§ Cost, ¢/1000 gal of plant influent

‡‡ Cost, ¢/1000 gal of plant influent/1000 ppm acidity as $CaCO_3$ (b.p. to pH 8.3)

2. RESULTS OF TREATMENT PLANT ANALYSIS

Refer to Table 4

3. RESULTS OF METAL ANALYSIS FROM THE CENTRAL LABORATORY

Refer to Table 5

4. PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

Refer to Table 6

5. PROPERTIES OF PLANT SLUDGE

A. Sludge settling behavior

Refer to Figure 1

B. Solids content (%) of sludges

Line 1	5.60
Line 2	1.79

TABLE 4 RESULTS OF TREATMENT PLANT ANALYSES

Parameter	Plant Influent			Line 1			Line 2		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Temperature (C)	16.4	18.7	17.4	17.3	18.9	17.9	17.1	19.0	18.1
pH	2.8	2.8	2.7	4.4	5.5	4.0	4.6	5.9	5.1
Acidity, b.p. to pH 8.3*	2300	2500	2400	150	640	350	56.8	417.4	189.5
Acidity, cold to 7.3, H_2O_2*	1900	2100	2000	69	420	220	13	190	74
Alkalinity*	0	0	0	11	93	23	-2.9	6.9	2.9
Specific conductance+	3000	4400	4000	3000	4300	3900	2600	4300	3900
Iron, ferrous, ppm	1.4	26	14	0.3	1.5	0.9	$<$0.10	0.7	0.4
Iron, ferric, ppm	270	290	280	0.4	1.8	1.2	$<$ 0.1	1.7	1.0
Sulfate, SO_4 ppm	3600	3600	3500	3000	3100	3100	3100	3200	3100

* ppm as $CaCO_3$

+ umhos/cm at 25C

TABLE 5 METAL ANALYSIS* (A.A. SPECTROPHOTOMETRY FROM CENTRAL LAB.)

Collection site	pH	Cu	Cr	Pb	Mn	Fe	Zn	Al	Ni	Mg	Ca
☐ Plant influent	2.78	0.16	0.06	0.04	56.0	300	5.31	100	2.28	222	200
☐ Aeration tank #1	4.98	0.11	0.03	0.10	50.0	3.00	3.81	29.3	2.26	221	679
☐ Aeration tank #2	5.11	0.06	0.03	0.09	46.0	1.10	4.64	4.20	1.99	225	803

*Results in mg/l; pH in standard units

TABLE 6 PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

PARAMETER	Percent removal/addition Line 1	 Line 2
Treatment pH	5.0	5.1
Acidity	89.00	96.30
Conductivity	2.50-	2.50-
Sulfate	11.50-	11.50-
Copper	31.30-	62.50-
Chromium	50.00-	50.00-
Lead	150.00+	125.00+
Manganese	10.80-	17.90-
Iron ABS	99.00-	99.70-
Zinc	28.30-	12.70-
Aluminum	81.70-	97.40-
Nickel	.90-	12.80-
Magnesium	.50-	1.30+
Calcium	239.50+	301.50+

* - indicates percent removal
+ + indicates percent addition

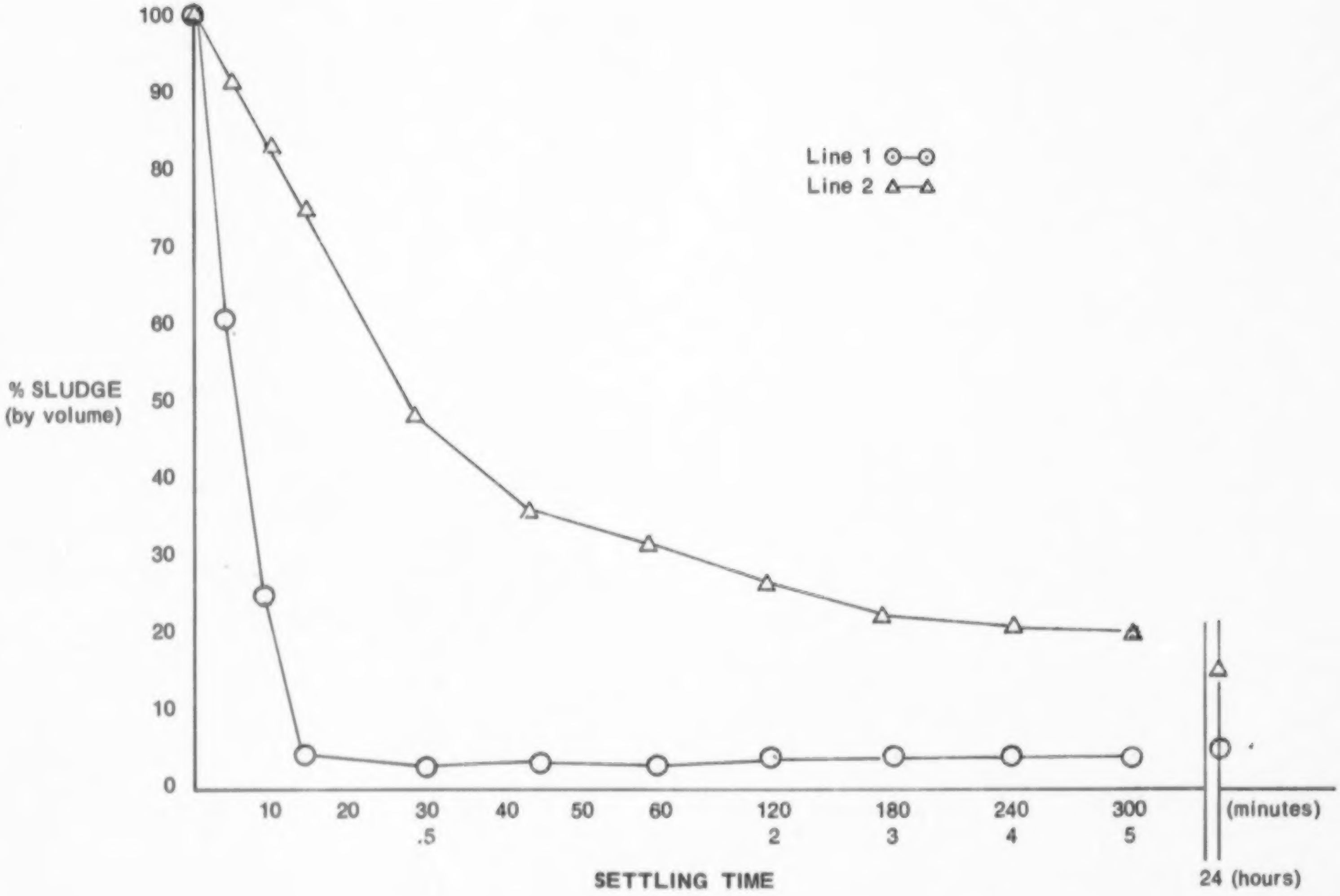


Figure 1.
SLUDGE SETTLING BEHAVIOR

WILL SCARLET WATER TREATMENT PLANT RESEARCH REPORT NO. 4

DATE May 29, 1973

I. DESCRIPTION OF RESEARCH STAGE

A. According to the research schedule, hydrated lime was used as the neutralizing reagent on both lines at a counterpoise weight of six pounds of lime per belt-foot. There was no sludge recirculation and the flow pattern was parallel (50/50). An effort was made to maintain both lines on pH 6.0.

B. For the research period, May 8-9, 1973, (48.0 hours of operation) the following summary of treatment was submitted:

TABLE I TREATMENT DISCHARGE VOLUMES*

Units	Total Water Influent	Line I Water Influent	Line 2 Water Influent
Gallons	6,050,880	3,631,680	2,419,200
Liters	22,919,523	13,756,077	9,163,445

*pH desired: Line I, 6.0; line 2, 6.0; Actual pH: Line I, 5.6;
Line 2, 6.0;
Influent, 2.7

TABLE 2 TREATMENT REQUIREMENT SUMMARY

Item	Line I	Line 2
Alkalinity added (mg/l as $CaCO_3$)	48.00	8.00
Sludge volume (% of initial volume after 24 hours)	3.50	18.60
Treatment required (lb chemical/1000 gal influent)	23.74	16.13

TABLE 3 TREATMENT COST SUMMARY

Line	Cost Unit*	Total Weight+	Water Influent#	¢/vol§	¢/vol/ppm‡‡
1	0.46	86,200	3,631,680	10.9	4.5
2	1.26	39,042	2,419,200	20.3	8.5
Subtotal:	--	125,242	6,050,880	--	-
Total (chemical only):		---	---	14.7	6.1
Total (operating):		---	---	21.9	9.1

* ¢/lb of chemical

+ lb of chemical

# Gal of water treated

§ Cost, ¢/1000 gal of plant influent

‡‡ Cost, ¢/1000 gal of plant influent/1000 ppm acidity as $CaCO_3$ (b.p. to pH 8.3)

2. RESULTS OF TREATMENT PLANT ANALYSIS

Refer to Table 4

3. RESULTS OF METAL ANALYSIS FROM THE CENTRAL LABORATORY

Refer to Table 5

4. PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

Refer to Table 6

5. PROPERTIES OF PLANT SLUDGE

A. Sludge settling behavior

Refer to Figure 1

B. Solids content (%) of sludges

Line 1	6.51
Line 2	1.92

TABLE 4 RESULTS OF TREATMENT PLANT ANALYSES

Parameter	Plant Influent			Line 1			Line 2		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Temperature (C)	18.0	19.0	18.6	17.8	20.1	8.8	17.8	20.0	18
pH	2.7	2.8	2.7	4.6	6.2	5.6	5.1	6.3	6.0
Acidity, b.p. to pH 8.3*	2300	2800	2400	50	560	180	44	110	57
Acidity, cold to 7.3, H_2O_2*	2000	2700	2200	22	320	93	12	44	19
Alkalinity*	0	0	0	1.6	72	48	3.1	10	7.5
Specific conductance+	3300	4500	4100	3400	4400	3800	3100	4500	4100
Iron, ferrous, ppm	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Iron, ferric, ppm	284.0	340.0	309.0	0.46	2.50	1.52	1.40	2.95	2.00
Sulfate, SO_4 ppm	3400	3600	3500	2800	3400	3000	3100	3500	3200

* ppm as $CaCO_3$

+ umhos/cm at 25C

TABLE 5 METAL ANALYSIS* (A.A. SPECTROPHOTOMETRY FROM CENTRAL LAB.)

Collection site	pH	Cu	Cr	Pb	Mn	Fe	Zn	Al	Ni	Mg	Ca
☐ Plant influent	2.73	0.19	0.08	0.06	62.0	320	5.75	190	2.29	250	220
☐ Aeration tank #1	5.56	0.14	0.06	0.12	57.0	1.98	2.85	4.63	2.24	240	750
☐ Aeration tank #2	6.01	0.07	0.06	0.11	45.0	2.17	2.75	2.17	2.15	245	930

*Results in mg/l; pH in standard units

TABLE 6 PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

PARAMETER	Percent removal/addition Line 1	 Line 2
Treatment pH	5.6	6.0
Acidity	95.80-	99.20-
Conductivity	5.00-	2.50+
Sulfate	14.30-	8.60-
Copper	45.50-	68.20-
Chromium	33.40-	50.00-
Lead	150.00+	200.00+
Manganese	3.20-	25.00-
Iron ABS	99.70-	99.70-
Zinc	13.10-	7.00-
Aluminum	98.00-	99.40-
Nickel	10.30-	18.80-
Magnesium	.80+	4.10+
Calcium	231.80+	327.20+

* - indicates percent removal
+ + indicates percent addition

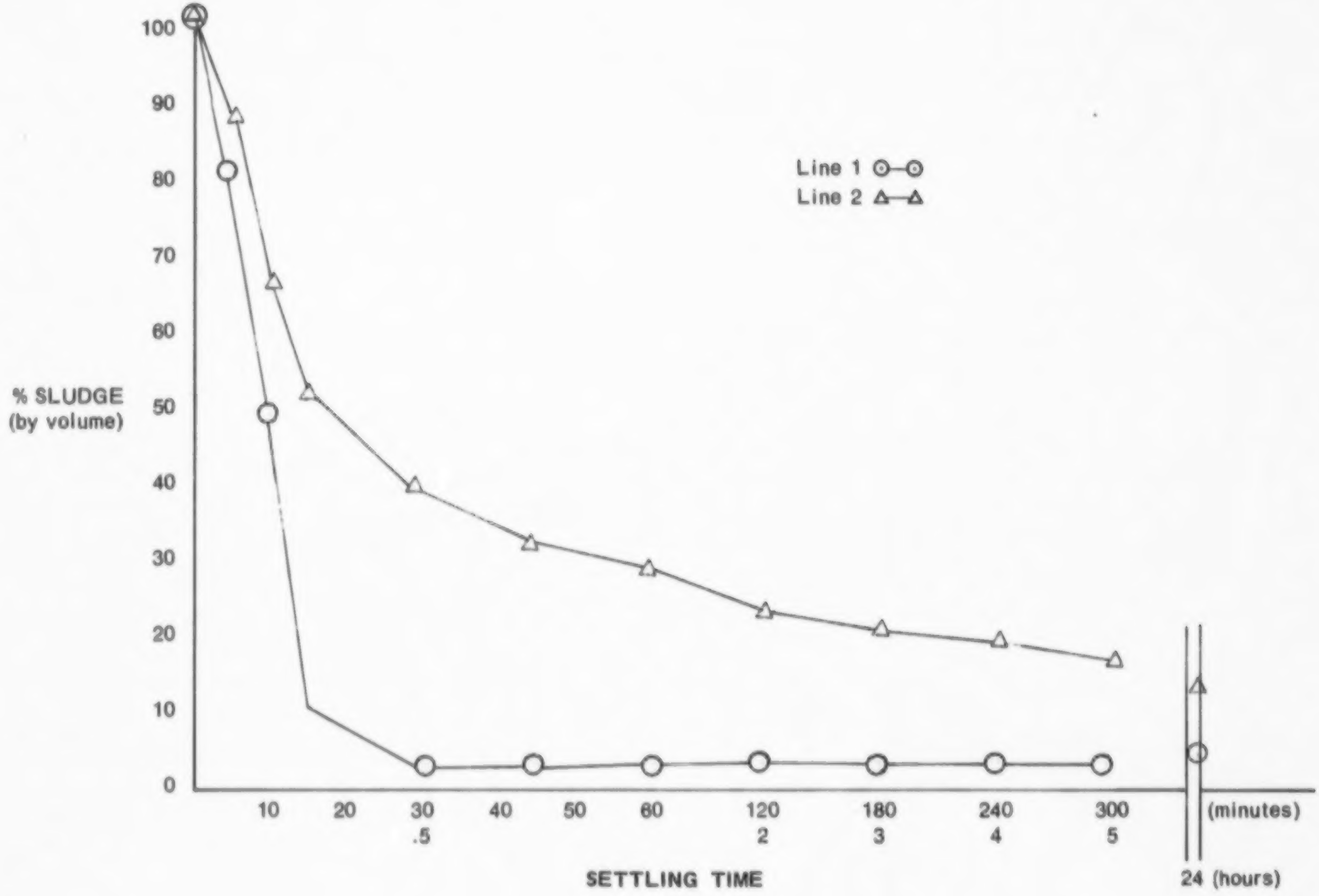


Figure 1.
SLUDGE SETTLING BEHAVIOR

WILL SCARLET WATER TREATMENT PLANT RESEARCH REPORT NO. 5

DATE June 5, 1973

I. DESCRIPTION OF RESEARCH STAGE

A. According to the research schedule, hydrated lime was used as the neutralizing reagent on both lines at a counterpoise weight of six pounds of lime per belt-foot. There was no sludge recirculation and the flow pattern was parallel (50/50). An effort was made to maintain line #1 at pH 5.0 and line #2 at pH 6.0.

B. For the research period, May 21-25, 1973, (96.0 hours of operation) the following summary of treatment is submitted:

TABLE 1 TREATMENT DISCHARGE VOLUMES*

Units	Total Water Influent	Line 1 Water Influent	Line 2 Water Influent
Gallons	12,096,000	7,257,600	4,838,400
Liters	45,817,228	27,490,337	18,326,891

*pH desired: Line 1, 5.0; line 2, 6.0; Actual pH: Line 1, 4.7
Line 2, 5.8
influent, 2.6

TABLE 2 TREATMENT REQUIREMENT SUMMARY

Item	Line 1	Line 2
Alkalinity added (mg/l as $CaCO_3$)	1.00	93.00
Sludge volume (% of initial volume after 24 hours)	5.00	5.00
Treatment required (lb chemical/1000 gal influent)	28.40	61.26

TABLE 3 TREATMENT COST SUMMARY

Line	Cost Unit*	Total Weight+	Water Influent#	¢/vol§	¢/vol/ppm‡‡
1	0.46	206,140	7,257,600	13.1	4.4
2	0.46	296,420	4,838,400	28.2	9.4
Subtotal:	--	502,560	12,096,000	--	-
Total (chemical only):		---	---	19.1	6.4
Total (operating):		---	---	26.1	8.9

* ¢/lb of chemical

+ lb of chemical

# Gal of water treated

§ Cost, ¢/1000 gal of plant influent

‡‡ Cost, ¢/1000 gal of plant influent/1000 ppm acidity as $CaCO_3$ (b.p. to pH 8.3)

2. RESULTS OF TREATMENT PLANT ANALYSIS

Refer to Table 4

3. RESULTS OF METAL ANALYSIS FROM THE CENTRAL LABORATORY

Refer to Table 5

4. PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

Refer to Table 6

5. PROPERTIES OF PLANT SLUDGE

A. Sludge settling behavior

Refer to Figure 1

B. Solids content (%) of sludges

Line	Solids content (%)
Line 1	6.42
Line 2	6.73

TABLE 4 RESULTS OF TREATMENT PLANT ANALYSES

Parameter	Plant Influent			Line 1			Line 2		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Temperature (C)	20.0	22.3	21.5	19.8	22.0	21.0	19.9	22.3	21.2
pH	2.6	2.6	2.6	4.5	4.80	4.7	5.7	6.0	5.8
Acidity, b.p. to pH 8.3*	2800	3300	3000	330	540	380	130	210	180
Acidity, cold to 7.3, H_2O_2*	2500	2800	2600	210	350	260	57	130	110
Alkalinity*	0	0	0	-17	8.6	0.6	76	110	93
Specific conductance+	4000	5100	4600	3700	5100	4500	3700	5200	4600
Iron, ferrous, ppm	8.7	10	9.3	0.1	2.2	0.9	0.1	2.0	0.8
Iron, ferric, ppm	226	371	329	0	3.1	1.6	0	2.8	1.3
Sulfate, SO_4 ppm	4500	4800	4600	3900	4500	4200	3800	4500	4200

* ppm as $CaCO_3$

+ umhos/cm at 25C

TABLE 5 METAL ANALYSIS* (A.A. SPECTROPHOTOMETRY FROM CENTRAL LAB.)

Collection site	pH	Cu	Cr	Pb	Mn	Fe	Zn	Al	Ni	Mg	Ca
☐ Plant influent	2.6	0.24	0.11	0.07	50.0	345	8.30	245	3.06	281	239
☐ Aeration tank #1	5.0	0.12	0.05	0.18	45.0	3.92	5.40	24.2	3.23	284	940
☐ Aeration tank #2	6.0	0.04	0.09	0.21	50.0	3.40	4.70	2.65	2.02	282	965

*Results in mg/l; pH in standard units

TABLE 6 PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

PARAMETER	Percent removal/addition	
	Line 1	Line 2
Treatment pH	4.7	5.8
Acidity	90.30-	96.00-
Conductivity	3.10-	.90-
Sulfate	9.30-	8.50-
Copper	50.00-	83.40-
Chromium	54.60-	18.20-
Lead	157.10+	200.00+
Manganese	10.00-	.00-
Iron ABS	98.90-	99.10-
Zinc	35.00-	43.40-
Aluminum	90.20-	99.00-
Nickel	5.50+	34.00-
Magnesium	1.00+	.30+
Calcium	293.30+	303.70+

* - indicates percent removal
+ + indicates percent addition

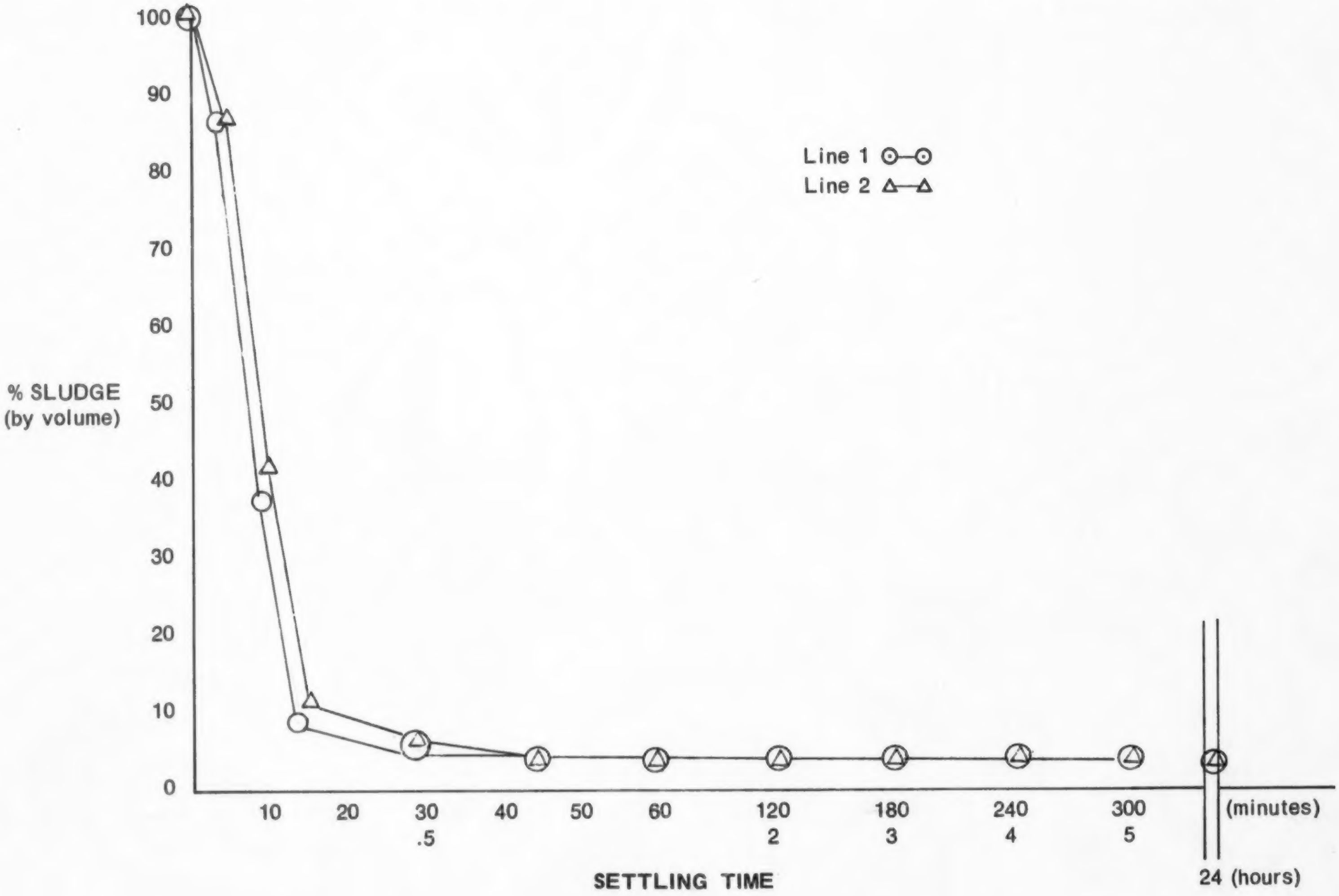


Figure 1.
SLUDGE SETTLING BEHAVIOR

WILL SCARLET WATER TREATMENT PLANT RESEARCH REPORT NO. 6

DATE June 29, 1973

I. DESCRIPTION OF RESEARCH STAGE

A. According to the research schedule, hydrated lime was used as the neutralizing reagent on both lines at a counterpoise weight of six pounds of lime per belt-foot. There was no sludge recirculation and the flow pattern was parallel (50/50). An effort was made to maintain line #1 at pH 4.0 and line #2 at pH 5.0.

B. For the research period, June 11-13, 1973, (72.0 hours of operation) the following summary of treatment is submitted:

TABLE 1 TREATMENT DISCHARGE VOLUMES*

Units	Total Water Influent	Line 1 Water Influent	Line 2 Water Influent
Gallons	8,856,000	5,313,600	3,542,400
Liters	33,544,756	20,126,854	13,417,902

*pH desired: Line 1, 4.0; line 2, 5.0; Actual pH: Line 1, 4.1
Line 2, 5.2
influent, 2.5

TABLE 2 TREATMENT REQUIREMENT SUMMARY

Item	Line 1	Line 2
Alkalinity added (mg/l as $CaCO_3$)	0.00	28.00
Sludge volume (% of initial volume after 24 hours)	2.50	5.00
Treatment required (lb chemical/1000 gal influent)	19.70	51.87

TABLE 3 TREATMENT COST SUMMARY

Line	Cost Unit*	Total Weight+	Water Influent#	¢/vol§	¢/vol/ppm‡‡
1	0.46	104,680	5,313,600	9.1	2.7
2	0.46	183,730	3,542,400	23.9	7.0
Subtotal:	--	288,410	8,856,000	--	-
Total (chemical only):		---	---	15.0	4.4
Total (operating):		---	---	22.5	6.6

* ¢/lb of chemical

+ lb of chemical

# Gal of water treated

§ Cost, ¢/1000 gal of plant influent

‡‡ Cost, ¢/1000 gal of plant influent/1000 ppm acidity as $CaCO_3$ (b.p. to pH 8.3)

2. RESULTS OF TREATMENT PLANT ANALYSIS

Refer to Table 4

3. RESULTS OF METAL ANALYSIS FROM THE CENTRAL LABORATORY

Refer to Table 5

4. PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

Refer to Table 6

5. PROPERTIES OF PLANT SLUDGE

A. Sludge settling behavior

Refer to Figure 1

B. Solids content (%) of sludges

Line 1	5.59
Line 2	6.21

TABLE 4 RESULTS OF TREATMENT PLANT ANALYSES

Parameter	Plant Influent			Line 1			Line 2		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Temperature (C)	28.4	30.9	29.5	28.3	30.1	29.1	28.2	29.8	28.9
pH	2.5	2.6	2.5	4.1	4.2	4.1	5.0	5.9	5.2
Acidity, b.p. to pH 8.3*	3300	3600	3400	900	1400	1300	130	240	190
Acidity, cold to 7.3, H_2O_2*	2600	2900	2800	590	970	840	88	140	120
Alkalinity*	0	0	0	0	0	0	12	65	28
Specific conductance+	3000	5000	4200	2900	4800	3800	3000	4800	3800
Iron, ferrous, ppm	20	25	29	0.1	1.5	0.7	0.1	0.1	0.1
Iron, ferric, ppm	316	345	321	0.8	7.3	4.4	1.5	2.1	1.8
Sulfate, SO_4 ppm	4000	4500	4800	3700	4400	4000	3400	3700	3600

* ppm as $CaCO_3$

+ umhos/cm at 25C

TABLE 5 METAL ANALYSIS* (A.A. SPECTROPHOTOMETRY FROM CENTRAL LAB.)

Collection site	pH	Cu	Cr	Pb	Mn	Fe	Zn	Al	Ni	Mg	Ca
☐ Plant influent	2.51	0.26	0.09	0.58	85.0	345	13.5	260	2.79	328	210
☐ Aeration tank #1	4.11	0.20	0.05	1.58	80.0	3.32	18.1	160	3.16	336	760
☐ Aeration tank #2	5.24	0.08	0.05	1.33	64.0	1.83	10.1	50.0	3.05	322	950

*Results in mg/l; pH in standard units

TABLE 6 PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

PARAMETER	Percent removal/addition Line 1	 Line 2
Treatment pH	4.1	5.2
Acidity	69.90-	95.80-
Conductivity	9.60-	9.60-
Sulfate	16.70-	25.00-
Copper	23.10-	69.30-
Chromium	44.50-	44.50-
Lead	.00-	129.30+
Manganese	5.90-	24.80-
Iron ABS	99.10-	99.50-
Zinc	34.00+	25.20-
Aluminum	38.50-	80.80-
Nickel	13.20+	9.30+
Magnesium	2.40+	1.90+
Calcium	261.90+	352.30+

* - indicates percent removal
+ + indicates percent addition

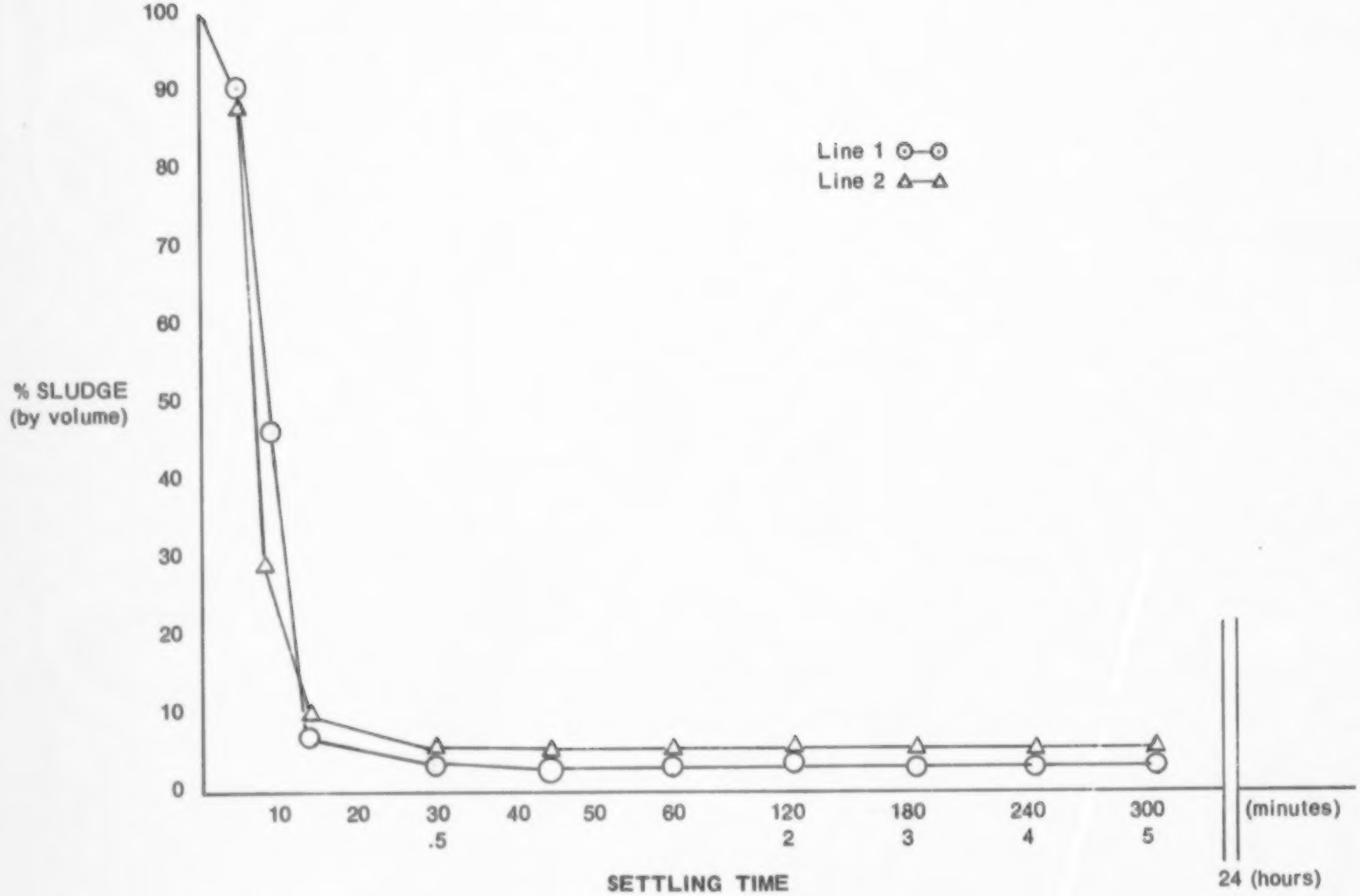


Figure 1.
SLUDGE SETTLING BEHAVIOR

WILL SCARLET WATER TREATMENT PLANT RESEARCH REPORT NO. 7

DATE June 29, 1973

I. DESCRIPTION OF RESEARCH STAGE

A. According to the research schedule, hydrated lime was used as the neutralizing reagent on both lines at a counterpoise weight of six pounds of lime per belt-foot. There was no sludge recirculation and the flow pattern was parallel (50/50). An effort was made to maintain line #1 at pH 4.5 and line #2 at pH 5.0.

B. For the research period, June 14-15, 1973, (48.0 hours of operation) the following summary of treatment is submitted:

TABLE I TREATMENT DISCHARGE VOLUMES*

Units	Total Water Influent	Line I Water Influent	Line 2 Water Influent
Gallons	5,904,000	3,542,400	2,361,600
Liters	22,363,171	13,417,902	8,945,268

*pH desired: Line I, 4.5; line 2, 5.0; Actual pH: Line I, 4.5
Line 2, 5.2
Influent, 2.5

TABLE 2 TREATMENT REQUIREMENT SUMMARY

Item	Line I	Line 2
Alkalinity added (mg/l as $CaCO_3$)	0.00	25.00
Sludge volume (% of initial volume after 24 hours)	4.00	5.00
Treatment required (lb chemical/1000 gal influent)	29.01	45.78

TABLE 3 TREATMENT COST SUMMARY

Line	Cost Unit*	Total Weight+	Water Influent#	¢/vol§	¢/vol/ppm‡‡
1	0.46	102,760	3,542,400	13.3	3.8
2	0.46	108,100	2,361,600	21.1	6.0
Subtotal:	--	210,860	5,904,000	--	-
Total (chemical only):		---	---	16.4	4.7
Total (operating):		---	---	23.9	6.8

* ¢/lb of chemical

+ lb of chemical

# Gal of water treated

§ Cost, ¢/1000 gal of plant influent

‡‡ Cost, ¢/1000 gal of plant influent/1000 ppm acidity as $CaCO_3$ (b.p. to pH 8.3)

2. RESULTS OF TREATMENT PLANT ANALYSIS

   Refer to Table 4

3. RESULTS OF METAL ANALYSIS FROM THE CENTRAL LABORATORY

   Refer to Table 5

4. PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

   Refer to Table 6

5. PROPERTIES OF PLANT SLUDGE

   A. Sludge settling behavior

      Refer to Figure 1

   B. Solids content (%) of sludges

Line 1	5.89
Line 2	6.45

TABLE 4 RESULTS OF TREATMENT PLANT ANALYSES

Parameter	Plant Influent			Line 1			Line 2		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Temperature (C)	26.8	29.7	28.2	25.5	29.6	27.4	25.3	29.0	27.4
pH	2.5	2.5	2.5	4.4	4.5	4.5	5.2	5.4	5.2
Acidity, b.p. to pH 8.3*	3300	3600	3500	470	600	520	88	190	140
Acidity, cold to 7.3, H_2O_2*	2800	3100	2900	290	340	310	68	93	85
Alkalinity*	0	0	0	-2	0	-1	20	33	25
Specific conductance+	4300	5000	4600	3900	4600	4300	3900	4600	4200
Iron, ferrous, ppm	20	24	22	∠0.1	∠0.1	∠0.1	∠0.1	∠0.1	∠0.1
Iron, ferric, ppm	340	354	347	1.9	2.0	1.9	∠0.1	1.2	0.8
Sulfate, SO_4 ppm	4500	4800	4600	3800	3900	3900	3900	3900	3900

* ppm as $CaCO_3$

+ umhos/cm at 25C

TABLE 5 METAL ANALYSIS* (A.A. SPECTROPHOTOMETRY FROM CENTRAL LAB.)

Collection site	pH	Cu	Cr	Pb	Mn	Fe	Zn	Al	Ni	Mg	Ca
☐ Plant influent	2.51	0.24	0.08	0.50	17.0	190	15.2	2.50	3.26	71.6	105
☐ Aeration tank #1	4.45	0.16	0.03	1.67	70.0	1.65	11.2	43.8	3.66	336	890
☐ Aeration tank #2	5.22	0.07	0.04	1.50	65.0	1.53	13.5	5.25	3.34	336	940

*Results in mg/l; pH in standard units

TABLE 6 PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

PARAMETER	Percent removal/addition Line 1	Line 2
Treatment pH	4.5	5.2
Acidity	89.70	96.60
Conductivity	6.60-	8.70-
Sulfate	62.50-	50.00
Copper	234.00+	200.00+
Chromium	311.70+	282.30+
Lead	99.20-	99.20-
Manganese	26.40-	11.20-
Iron ABS	82.50-	79.00-
Zinc	12.20+	2.40+
Aluminum	369.20+	369.20+
Nickel	747.60+	795.20+

* - indicates percent removal
+ + indicates percent addition

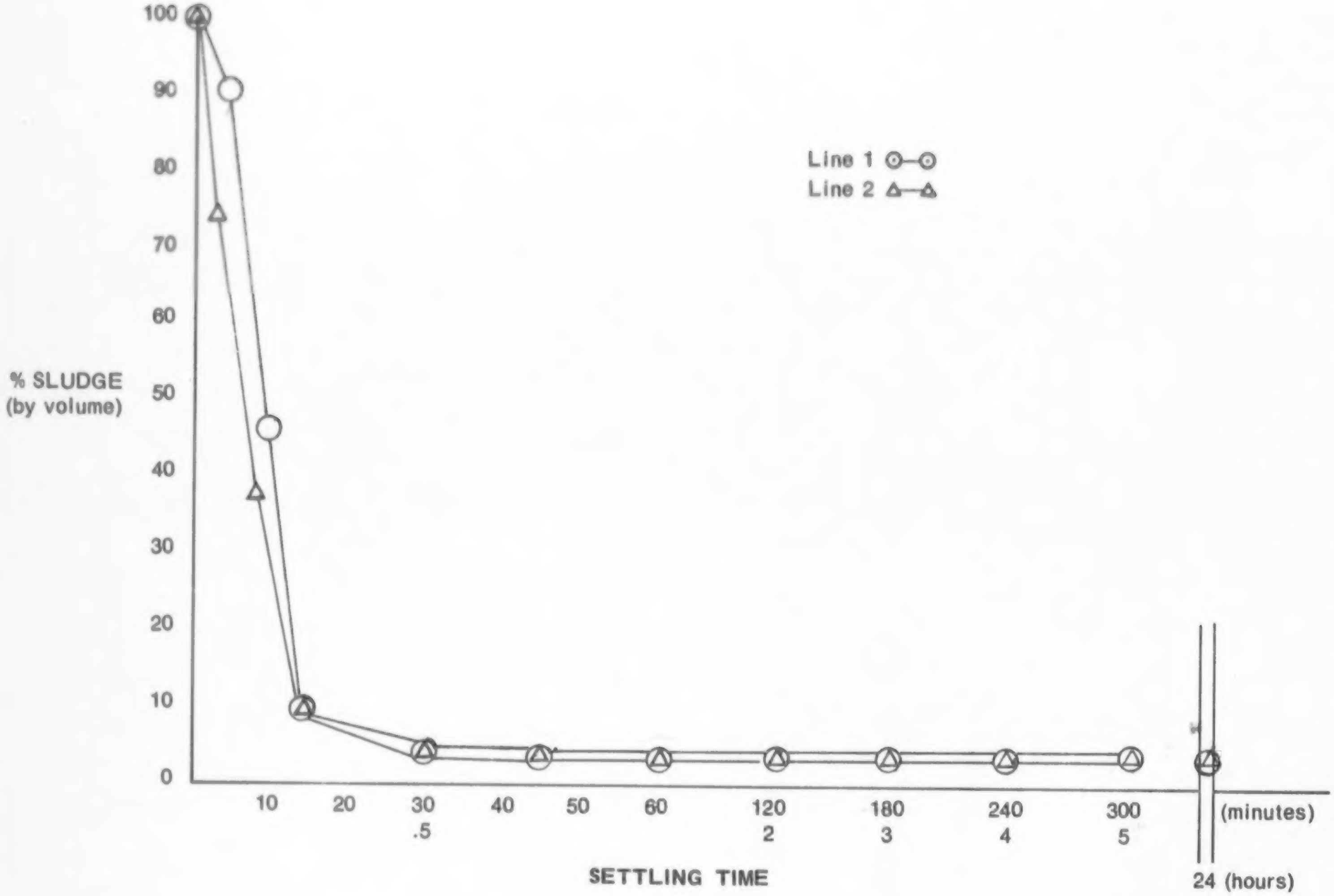


Figure 1.
SLUDGE SETTLING BEHAVIOR

WILL SCARLET WATER TREATMENT PLANT RESEARCH REPORT NO. 8

DATE October 23, 1973

1. In accordance with the original research schedule (Stanley Consultants, Inc., November 1971) and the revised research schedule (Peabody Coal Company, October 1973), an effort was made to operate the plant with a series flow pattern, no sludge recirculation. The neutralizing agent used on both lines was hydrated lime. The schedule called for a treatment pH of 5.0 on line #1 effluent, which was recirculated back thru line #2, with a final effluent pH of 7.0 as the projected goal.

2. After eight hours of plant operation, the results of analyses of two sets of research samples (Enclosure 1) and numberous plant operator checks (Enclosure 2) revealed that it was operationally impossible to reduce the final effluent pH below pH 8.0 to the desired treatment pH 7.0, as outlined in the research schedule.

3. In an effort to define the problem as it relates to treatment requirements, I performed two different titration curves (Enclosure 3). It was discovered that in series flow treatment, as outlined in paragraph 1 above, hydrated lime treatment of the raw plant influent to pH 5.0 neutralized 37-88% of the influent acidity. Thus, the chemical requirement placed on the #2 treatment line was so small (pH 5.0 to pH 7.0) that the BIF feeder could not deliver the neutralizing agent in such diminutive amounts.

4. Based on the operational information, Research Stages 8 and 8A cannot be achieved at the Will Scarlet Water Treatment Plant with the existing plant design and equipment.

Encl. #1 Sample Analyses
#2 Ops. Log
#3 Titration Data

ENCLOSURE 1 WATER QUALITY ANALYSES, WILL SCARLET WATER TREATMENT PLANT

	Plant	Influent	Line 1		Line 2	
Time of Sampling	1200	1500	1200	1500	1200	1500
Temperature (C)	13.9	16.4	14.2	16.3	14.0	16.3
pH	2.6	2.6	5.2	4.9	10.2	8.2
Acidity, b.p. to pH 8.3, ppm as $CaCO_3$	3200	3300	183	275	0	60
Acidity, H_2O_2, to pH 7.3, ppm as $CaCO_3$	3000	3100	87	129	0	0
Alkalinity, ppm as $CaCO_3$	0	0	23	3.5	120	18
Specific Conductivity, umhos/cm at 25C	4000	4120	4200	4200	4200	4200
Iron, total, ppm	550	564	2.5	2.5	0.5	2.2
Iron, ferrous, ppm	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Iron, ferric, ppm	550	564	2.5	2.5	0.8	2.2

ENCLOSURE 2 OPERATOR'S LONG SHEET DATA FOR RESEARCH STAGE NO. 3

	Line 1		Line 2	
Time	pH	Belt speed(%)*	pH	Belt speed(%)*
8:00 a.m.	--	73.0	--	60.0
11:00 a.m.	5.2	62.0	10.3	40.0
12:00 noon	5.3	62.0	9.5	30.0
1:00 p.m.	4.9	62.0	9.1	20.0
2:00 p.m.	4.8	62.0	8.3	16.0
3:00 p.m.	4.8	62.0	8.1	15.0

* Service engineer for BIF gravimetric feeders suggests operation between 40-70% belt speed

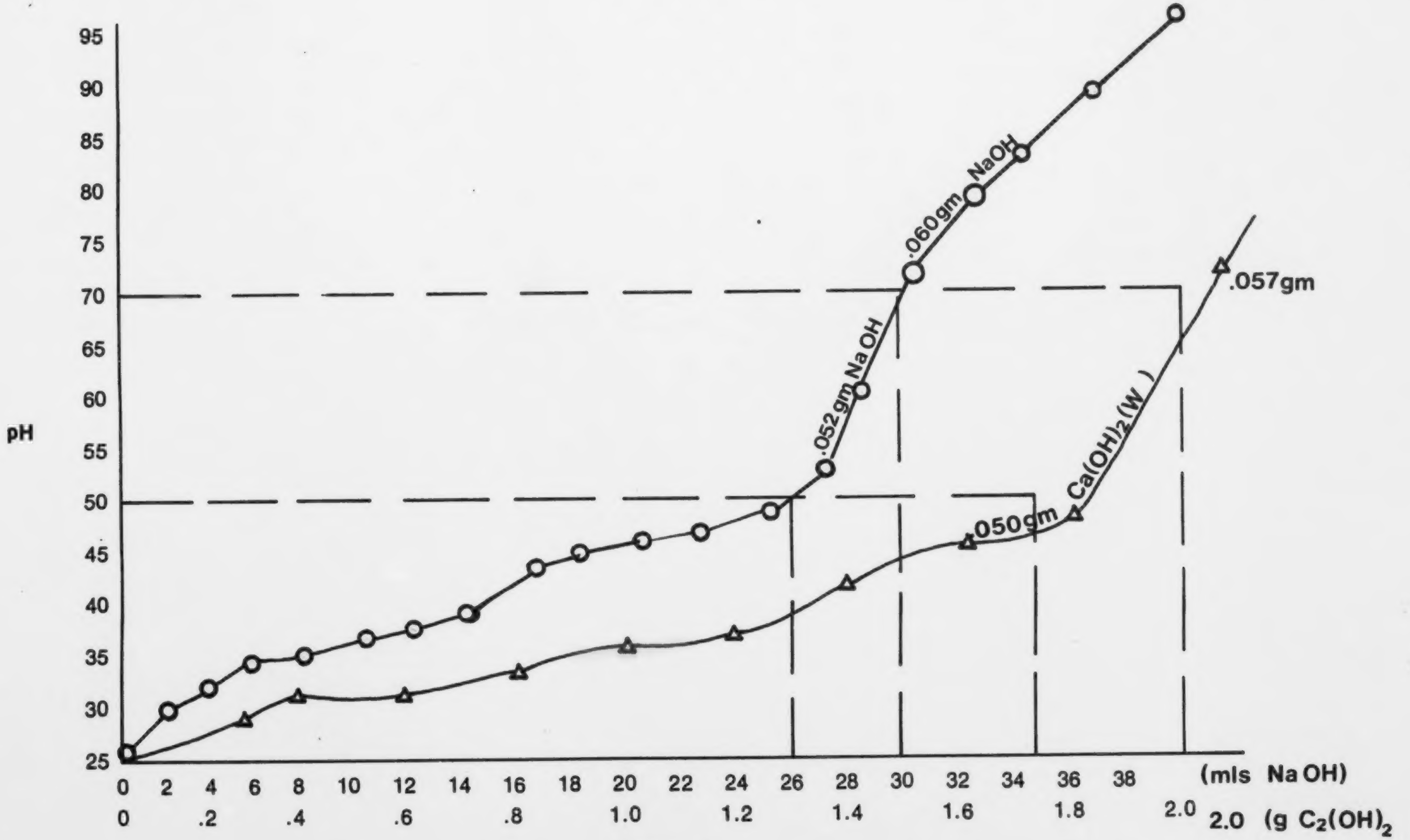


Figure 1
NEUTRALIZATION TITRATION CURVE FOR PLANT INFLUENT, OCTOBER 29, 1973

WILL SCARLET WATER TREATMENT PLANT RESEARCH REPORT NO. 8A

DATE October 28, 1973

1. According to the original research schedule (Stanley Consultants, Inc., November 1971) and the revised research schedule (Peabody Coal Company, October 1973), an effort was made to operate the treatment plant in a series flow pattern, no sludge recirculation, using hydrated lime as the neutralizing agent on both treatment lines at a counterpoise weight of six pounds per belt-foot. The pH criteria was pH 5.0 on line #1 effluent and pH 7.0 on line #2 effluent, with no aeration on the No. 2 side.

2. Originally scheduled as Research Stage No. 8, this research stage was found to be operationally impossible. The reader is referred to Research Report No. 8 for a determination and reasoning behind the elimination of these research stages.

WILL SCARLET WATER TREATMENT PLANT RESEARCH REPORT NO. 9

DATE November 10, 1973

I. DESCRIPTION OF RESEARCH STAGE

A. According to the research schedule, rotary hydrated lime was used as the treatment reagent on both lines at a counterpoise weight of six pounds per belt-foot. There was no sludge recirculation and the flow pattern was series (100/100). An effort was made to maintain line #1 at pH 4.0 and line #2 at pH 7.0.

B. For the research period, October 30-31, 1973, (32.0 hours of operation) the following summary of treatment is submitted:

TABLE 1 TREATMENT DISCHARGE VOLUMES*

Units	Total Water Influent	Line 1 Water Influent	Line 2 Water Influent
Gallons	6,144,000	6,144,000	6,144,000
Liters	23,272,243	23,272,243	23,272,243

*pH desired: Line 1, 4.0; line 2, 7.0. Actual pH: Line 1, 3.8
Line 2, 6.6
influent, 2.5

TABLE 2 TREATMENT REQUIREMENT SUMMARY

Item	Line 1	Line 2
Alkalinity added (mg/l as $CaCO_3$)	0.00	5.00
Sludge volume (% of initial volume after 24 hours)	3.00	13.00
Treatment required (lb chemical/1000 gal influent)	10.91	7.42

TABLE 3 TREATMENT COST SUMMARY

Line	Cost Unit*	Total Weight+	Water Influent#	¢/vol§	¢/vol/ppm‡‡
1	1.26	67,068	6,144,000	13.8	2.9
2	1.26	45,600	6,144,000	9.4	2.0
Subtotal:	--	112,668	6,144,000	--	---
Total (chemical only):		---	---	23.1	4.9
Total (operating):		---	---	28.8	6.1

* ¢/lb of chemical

+ lb of chemical

# Gal of water treated

§ Cost, ¢/1000 gal of plant influent

‡‡ Cost, ¢/1000 gal of plant influent/1000 ppm acidity as $CaCO_3$ (b.p. to pH 8.3)

2. RESULTS OF TREATMENT PLANT ANALYSIS

   Refer to Table 4

3. RESULTS OF METAL ANALYSIS FROM THE CENTRAL LABORATORY

   Refer to Table 5

4. PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

   Refer to Table 6

5. PROPERTIES OF PLANT SLUDGE

   A. Sludge settling behavior

      Refer to Figure 1

   B. Solids content (%) of sludges

      Line 1 (at pH 3.8) 4.61%

      Line 2 (at pH 7.0) 4.95%

TABLE 4 RESULTS OF TREATMENT PLANT ANALYSES

Parameter	Plant Influent			Line 1			Line 2		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Temperature (C)	14.1	20.1	16.9	14.3	20.5	17.1	14.5	20.4	17.1
pH		2.7	2.5	3.6	4.3	3.9	6.4	7.0	6.8
Acidity, b.p. to pH 8.3*	3500	5300	4700	930	2700	1900	64	92	80
Acidity, cold to 7.3, H_2O_2*	3100	4700	4100	512	1900	1300	17	42	27
Alkalinity*	0	0	0	0	0	0	3.4	6.5	5.0
Specific conductance+	4600	7000	4500	4100	7200	6200	3400	6900	5300
Iron, ferrous, ppm	0.1	33.0	13.1	0.1	0.1	0.1	0.1	0.1	0.1
Iron, ferric, ppm	664	930	800	2.7	6.4	4.4	0.1	0.9	0.4
Sulfate, SO_4 ppm	5200	5600	5400	5000	5400	5200	5200	5400	5300

* ppm as $CaCO_3$

+ umhos/cm at 25C

TABLE 5 METAL ANALYSIS* (A.A. SPECTROPHOTOMETRY FROM CENTRAL LAB.)

Collection site	pH	Cu	Cr	Pb	Mn	Fe	Zn	Al	Ni	Mg	Ca
☐ Plant influent	2.5	0.23	0.05	0.08	185	784	17.2	270	3.98	nd	100
☐ Line #1	4.0	0.21	0.04	0.23	180	17.9	15.8	260	4.56	nd	148
☐ Line #2	7.0	0.03	0.02	0.19	110	0.61	0.38	1.35	2.05	nd	102

*Results in mg/l; pH in standard units

TABLE 6 PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

PARAMETER	Percent removal/addition		
	Line 1	Line 2	Total
Acidity	59.60-*	95.80-	98.30-
Conductivity	37.70++	14.60-	17.70+
Sulfate	3.80-	1.90+	1.90-
Copper	8.70-	85.80-	87.00-
Chromium	20.00-	50.00-	60.00-
Lead	187.50+	17.40-	137.50+
Manganese	2.80-	38.90-	40.60-
Iron ABS	97.80-	96.60-	97.80-
Zinc	8.20-	97.60-	97.80-
Aluminum	3.80-	99.50-	99.50-
Nickel	14.50+	55.10-	48.50-
Magnesium	22.20+	9.00+	33.30+
Calcium	48.00+	31.10-	2.00+

* - indicates percent removal
+ + indicates percent addition

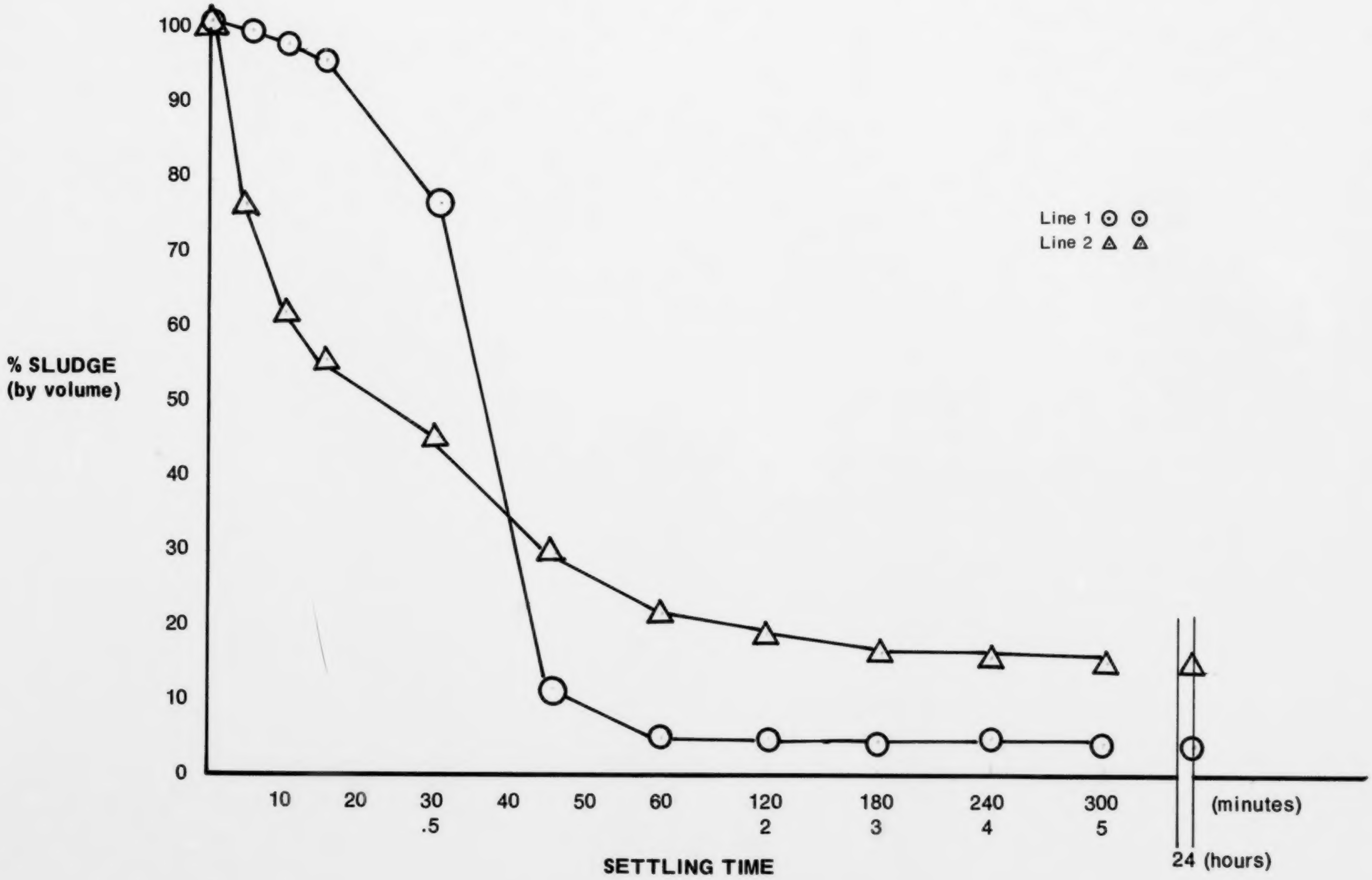


Figure I. SLUDGE SETTLING BEHAVIOR

WILL SCARLET WATER TREATMENT PLANT RESEARCH REPORT NO. 10

DATE November 19, 1973

I. DESCRIPTION OF RESEARCH STAGE

A. According to the research schedule, rotary hydrated lime was used as the treatment reagent on both lines at a counterpoise weight of six pounds per belt-foot. There was no sludge recirculation and the flow pattern was series (100/100). An effort was made to maintain line #1 effluent at pH 4.0 and line #2 effluent at pH 6.0.

B. For the research period, November 1-2, 1973, (16.8 hours of operation) the following summary of treatment is submitted:

TABLE 1 TREATMENT DISCHARGE VOLUMES*

Units	Total Water Influent	Line 1 Water Influent	Line 2 Water Influent
Gallons	3,033,600	3,033,600	3,033,600
Liters	11,490,670	11,490,670	11,490,670

*pH desired: Line 1, 4.0; line 2, 6.0; Actual pH: Line 1, 3.9
Line 2, 5.8
influent, 2.5

TABLE 2 TREATMENT REQUIREMENT SUMMARY

Item	Line 1	Line 2
Alkalinity added (mg/l as $CaCO_3$)	0.00	4.00
Sludge volume (% of initial volume after 24 hours)	5.00	18.00
Treatment required (lb chemical/1000 gal influent)	12.63	6.73

TABLE 3 TREATMENT COST SUMMARY

Line	Cost Unit*	Total Weight+	Water Influent#	¢/vol§	¢/vol/ppm‡‡
1	1.26	38,322	3,033,600	15.9	2.7
2	1.26	20,430	3,033,600	8.5	1.4
Subtotal:	--	58,752	3,033,600	--	---
Total (chemical only):		---	---	24.4	4.1
Total (operating):		---	---	36.3	6.1

* ¢/lb of chemical

+ lb of chemical

# Gal of water treated

§ Cost, ¢/1000 gal of plant influent

‡‡ Cost, ¢/1000 gal of plant influent/1000 ppm acidity as $CaCO_3$ (b.p. to pH 8.3)

2. RESULTS OF TREATMENT PLANT ANALYSIS

Refer to Table 4

3. RESULTS OF METAL ANALYSIS FROM THE CENTRAL LABORATORY

Refer to Table 5

4. PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

Refer to Table 6

5. PROPERTIES OF PLANT SLUDGE

A. Sludge settling behavior

Refer to Figure 1

B. Solids content (%) of sludges

Line 1	(pH 4.0)	4.58%
Line 2	(pH 6.0)	4.75%

TABLE 4 RESULTS OF TREATMENT PLANT ANALYSES

Parameter	Plant Influent			Line 1			Line 2		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Temperature (C)	13.8	14.3	14.1	13.9	14.4	14.1	13.9	14.4	14.2
pH	2.5	2.6	2.5	3.6	4.2	3.9	5.0	6.6	5.7
Acidity, b.p. to pH 8.3*	5800	6200	6000	1000	2700	2100	64	280	140
Acidity, cold to 7.3, H_2O_2*	4700	4800	4700	850	1700	1300	32	140	65
Alkalinity*	0	0	0	0	0	0	1.3	5.7	3.6
Specific conductance+	6100	7400	7000	5500	6800	6400	4900	5800	5400
Iron, ferrous, ppm	26	32	30	0.1	0.1	0.1	0.1	0.1	0.1
Iron, ferric, ppm	810	840	830	2.4	5.6	3.3	0.2	1.0	0.6
Sulfate, SO_4 ppm	5200	5600	5400	5000	5400	5200	5000	5400	5200

* ppm as $CaCO_3$

+ umhos/cm at 25C

TABLE 5 METAL ANALYSIS* (A.A. SPECTROPHOTOMETRY FROM CENTRAL LAB.)

Collection site	pH	Cu	Cr	Pb	Mn	Fe	Zn	Al	Ni	Mg	Ca
☐ Plant influent	2.5	0.19	0.05	0.08	200	790	16.7	270	4.40	nd+	98
☐ Line #1	4.0	0.17	0.04	0.23	195	10.9	15.8	240	5.13	nd+	165
☐ Line #2	6.0	0.05	0.05	0.15	150	0.43	3.62	3.80	3.38	nd+	136

*Results in mg/l; pH in standard units

TABLE 6 PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

PARAMETER	Percent removal/addition		
	Line 1	Line 2	Total
Acidity	72.40-*	95.00-	98.70-
Conductivity	8.60-	15.70-	22.90-
Sulfate	3.80-	.00-	3.80-
Copper	10.60-	70.60-	73.70-
Chromium	20.00-	25.00++	.00-
Lead	187.50+	34.80-	87.50+
Manganese	2.50-	23.10-	25.00-
Iron ABS	98.70-	96.10-	100.00-
Zinc	5.40-	77.10-	78.40-
Aluminum	11.20-	98.50-	98.60-
Nickel	16.50+	34.20-	23.20-
Magnesium	12.00+	19.60+	34.00+
Calcium	68.20+	17.60-	38.70+

* - indicates percent removal
+ + indicates percent addition

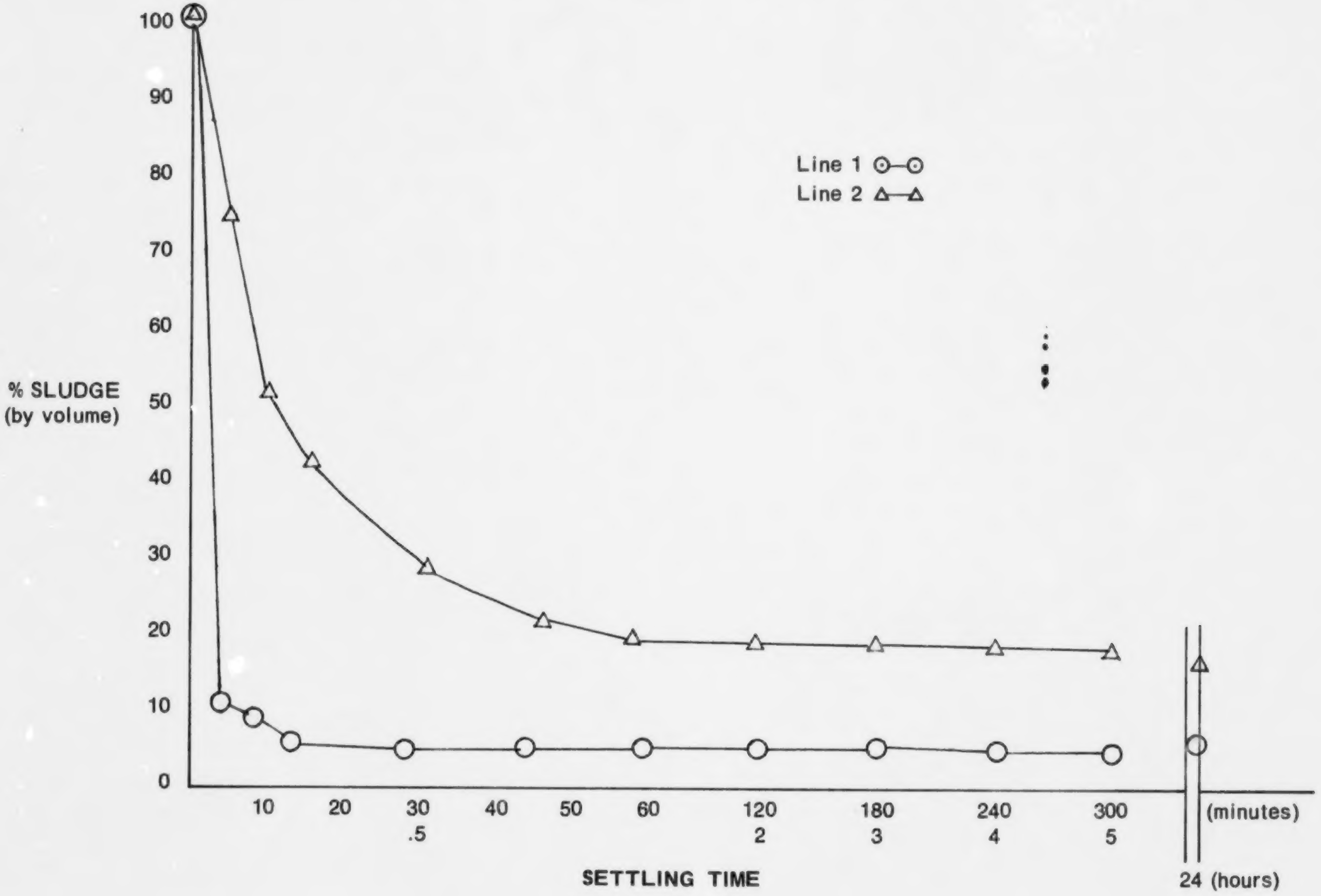


Figure 1.
SLUDGE SETTLING BEHAVIOR

WILL SCARLET WATER TREATMENT PLANT RESEARCH REPORT NO. 11

DATE November 19, 1973

I. DESCRIPTION OF RESEARCH STAGE

A. According to the research schedule, rotary hydrated lime was used on the treatment agent on both treatment lines at a counterpoise weight of six pounds per belt-foot. Sludge was recirculated to the rapid-mixers, each to its respective side at a rate of 88.3 GPM on line #1 and 94.8 GPM on line #2. The flow pattern was series (100/100) and the treatment line effluent pH's that were attempted were pH 4.0 on line #1 and pH 7.0 on line #2.

B. For the research period, November 5-6, 1973, (28.8 hours of operation) the following summary is submitted:

TABLE I TREATMENT DISCHARGE VOLUMES*

Units	Sludge volume	Water influent	Sludge/water ratio
Line 1			
Gallons	217,952	5,529,600	.057
Liters	1,204,338	20,945,018	
Line 2			
Gallons	286,848	5,529,600	.051
Liters	1,086,522	20,945,018	
Total			
Gallons	604,800	5,529,600	.109
Liters	2,290,861	20,945,018	

*pH desired: Line 1, 4.0; Line 2, 7.0. Actual pH: Line 1, 4.0; Line 2, 7.0; influent, 2.6

TABLE 2 TREATMENT REQUIREMENT SUMMARY

	Line 1	Line 2
Alkalinity added (mg/l as $CaCO_3$)	0.00	8.00
Sludge volume (% of initial volume after 24 hours)	9.00	13.00
Treatment required (lb chemical/1000 gal influent)	13.01	8.15

TABLE 3 TREATMENT COST SUMMARY

Line	Cost Unit*	Total Weight+	Water Influent#	¢/vol §	¢/vol/ppm‡‡
1	1.26	71,976	5,529,600	16.4	3.5
2	1.26	45,078	5,529,600	10.3	2.2
Subtotal:	--	117,054	5,529,600	--	---
Total (chemical only):		---	---	26.7	5.7
Total (operating):		---	---	32.6	7.8

* ¢/lb of chemical

+ lb of chemical

‡‡ Gal of water treated

§ Cost, ¢/1000 gal of plant influent

# Cost, ¢/1000 gal of plant influent/1000 ppm acidity as $CaCO_3$ (b.p. to pH 8.3)

2. RESULTS OF TREATMENT PLANT ANALYSIS

   Refer to Table 4

3. RESULTS OF METAL ANALYSIS FROM THE CENTRAL LABORATORY

   Refer to Table 5

4. PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

   Refer to Table 6

5. PROPERTIES OF PLANT SLUDGE

   A. Sludge settling behavior

      Refer to Figure 1

   B. Solids content (%) of sludges

Line 1	(pH 4.2)	3.84%
Line 2	(pH 7.0)	4.24%

TABLE 4 RESULTS OF TREATMENT PLANT ANALYSES

Parameter	Plant Influent			Line 1			Line 2		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Temperature (C)	10.5	13.2	11.8	10.3	13.6	11.9	10.3	13.6	11.9
pH	2.6	2.7	2.6	4.0	4.3	4.1	6.8	7.3	6.9
Acidity, b.p. to pH 8.3*	4100	5200	4700	870	2800	1900	45	72	56
Acidity, cold to 7.3, H_2O_2*	3300	4600	4000	510	1700	1200	15	25	21
Alkalinity*	0	0	0	0	0	0	7.3	8.8	8.0
Specific conductance+	5300	8000	6600	5100	7300	6200	4600	6400	5700
Iron, ferrous, ppm	10	20	15	0.1	0.1	0.1	0.1	0.1	0.1
Iron, ferric, ppm	610	860	750	2.4	5.0	4.0	0.2	1.3	0.9
Sulfate, SO_4 ppm	6400	6500	6500	5200	5300	5300	5200	5300	5300

* ppm as $CaCO_3$

+ umhos/cm at 25C

TABLE 5 METAL ANALYSIS* (A.A. SPECTROPHOTOMETRY FROM CENTRAL LAB.)

Collection site	pH	Cu	Cr	Pb	Mn	Fe	Zn	Al	Ni	Mg	Ca
☐ Plant influent	2.6	0.18	0.05	0.36	150	735	16.0	270	4.87	450	215
☐ Line #1	4.0	0.13	0.04	0.57	130	10.1	14.0	195	6.34	450	505
☐ Line #2	7.0	0.04	0.04	0.57	90.0	1.15	2.70	1.75	4.08	500	520

*Results in mg/l; pH in standard units

TABLE 6 PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

PARAMETER	Percent removal/addition Line 1	 Line 2	 Total
Acidity	70.00-*	98.30-	99.50-
Conductivity	6.10-	8.10-	13.70-
Sulfate	18.50-	.00-	18.50-
Copper	27.80-	69.30-	77.80-
Chromium	20.00-	.00-	20.00-
Lead	58.30+	.00-	58.30++
Manganese	13.40-	30.80-	40.00-
Iron ABS	98.70-	88.70-	99.90-
Zinc	12.50-	80.80-	83.20-
Aluminum	27.80-	99.20-	99.40-
Nickel	30.10+	35.70-	16.80-
Magnesium	.00-	11.10+	11.10+
Calcium	134.80+	2.90+	141.80+

* - indicates percent removal
+ + indicates percent addition

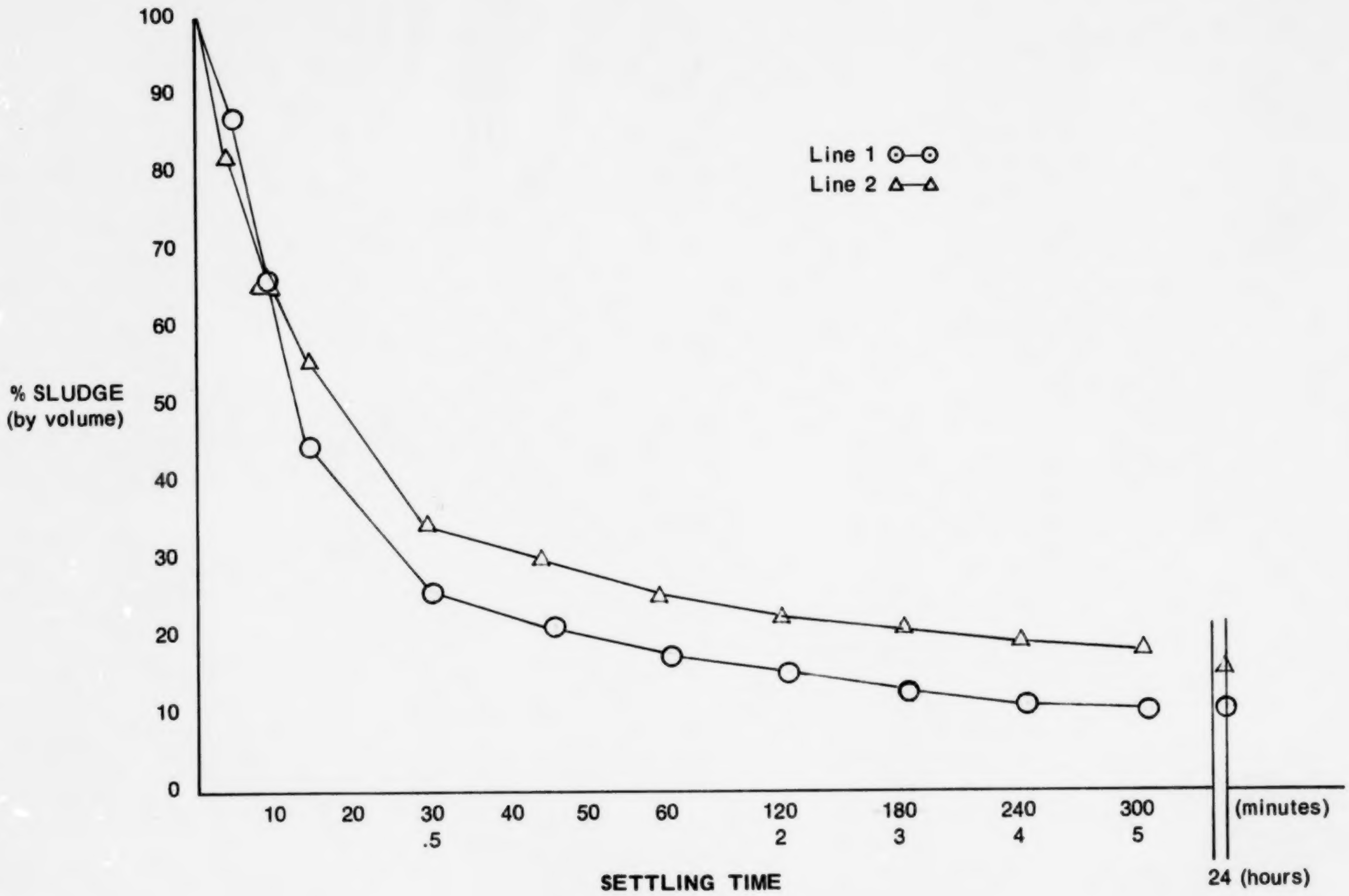


Figure 1.
SLUDGE SETTLING BEHAVIOR

WILL SCARLET WATER TREATMENT PLANT RESEARCH REPORT NO. 12

DATE November 19, 1973

I. DESCRIPTION OF RESEARCH STAGE

A. According to the research schedule, rotary hydrated lime was used on the treatment agent on both treatment lines at a counterpoise weight of six pounds per belt-foot. Sludge was recirculated to the rapid-mixers, each to its respective side at a rate of 83.3 GPM on line #1 and 94.8 GPM on line #2. The flow pattern was series (100/100) and the treatment line effluent pH's that were attempted were pH 4.0 on line #1 and pH 6.0 on line #2.

B. For the research period, November 8-10, 1973, (30.8 hours of operation), the following summary is submitted:

TABLE I TREATMENT DISCHARGE VOLUMES*

Units	Sludge volume	Water influent	Sludge/water ratio
	Line 1		
Gallons	340,032	4,500,000	.075
Liters	1,287,973	17,032,500	
	Line 2		
Gallons	306,768	4,500,000	.075
Liters	1,161,975	17,032,500	
	Total		
Gallons	646,800	4,500,000	.145
Liters	2,449,949	17,032,500	

*pH desired: Line 1, 4.0; Line 2, 6.0. Actual pH: Line 1, 4.0, Line 2, 6.2; influent 2.6

TABLE 2 TREATMENT REQUIREMENT SUMMARY

	Line 1	Line 2
Alkalinity added (mg/l as $CaCO_3$)	0.00	5.00
Sludge volume (% of initial volume after 24 hours)	10.00	15.00
Treatment required (lb chemical/1000 gal influent)	17.17	10.36

TABLE 3 TREATMENT COST SUMMARY

Line	Cost Unit*	Total Weight+	Water Influent#	¢/vol §	¢/vol/ppm++
1	1.26	77,256	4,500,000	21.6	3.4
2	1.26	46,620	4,500,000	13.1	2.0
Subtotal:	--	123,876	4,500,000	--	---
Total (chemical only):		---	---	34.7	5.4
Total (operating):		---	---	42.7	6.7

* ¢/lb of chemical
+ lb of chemical
++ Gal of water treated
§ Cost, ¢/1000 gal of plant influent
# Cost, ¢/1000 gal of plant influent/1000 ppm acidity as $CaCO_3$ (b.p. to pH 8.3)

2. RESULTS OF TREATMENT PLANT ANALYSIS

   Refer to Table 4

3. RESULTS OF METAL ANALYSIS FROM THE CENTRAL LABORATORY

   Refer to Table 5

4. PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

   Refer to Table 6

5. PROPERTIES OF PLANT SLUDGE

   A. Sludge settling behavior

      Refer to Figure 1

   B. Solids content (%) of sludges

Line 1	(pH 4.0)	5.67%
Line 2	(pH 7.0)	5.92%

TABLE 4 RESULTS OF TREATMENT PLANT ANALYSES

Parameter	Plant Influent			Line 1			Line 2		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Temperature (C)	8.5	14.1	11.1	8.5	14.2	11.1	8.6	14.1	11.2
pH	2.6	2.7	2.6	3.9	4.1	4.0	5.9	6.4	6.1
Acidity, b.p. to pH 8.3*	6000	6900	6400	1800	2500	2100	54	120	89
Acidity, cold to 7.3, H_2O_2*	4400	5100	4800	1300	1700	1500	32	74	61
Alkalinity*	0	0	0	0	0	0	2.7	8.3	5.3
Specific conductance+	6100	7800	7000	5900	6800	6400	4600	6200	5600
Iron, ferrous, ppm	9.4	15	12	0.10	0.1	0.1	0.1	0.1	0.1
Iron, ferric, ppm	820	910	860	3.3	3.9	3.6	0.2	0.4	0.3
Sulfate, SO_4 ppm	6700	6900	6800	5300	5500	5400	5300	5400	5400

* ppm as $CaCO_3$

+ umhos/cm at 25C

TABLE 5 METAL ANALYSIS* (A.A. SPECTROPHOTOMETRY FROM CENTRAL LAB.)

Collection site	pH	Cu	Cr	Pb	Mn	Fe	Zn	Al	Ni	Mg	Ca
☐ Plant influent	2.6	0.19	0.12	0.43	215	865	17.4	305	5.73	500	225
☐ Line 1	4.0	0.15	0.11	0.64	195	4.90	16.2	225	6.62	550	480
☐ Line 2	6.2	0.04	0.02	0.57	133	1.20	1.48	1.05	4.28	525	390

*Results in mg/l; pH in standard units

TABLE 6 PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

PARAMETER	Percent removal/addition Line 1	 Line 2	 Total
Acidity	68.60-*	96.00-	98.80-
Conductivity	8.60-	12.50-	20.00-
Sulfate	20.60-	.00-	20.60-
Copper	21.10-	73.40-	79.00-
Chromium	8.40-	81.90-	83.40-
Lead	48.80+[+]	11.00-	32.50+
Manganese	9.40-	31.80-	38.20-
Iron ABS	99.50-	75.60-	99.90-
Zinc	6.90-	90.90-	91.50-
Aluminum	26.30-	99.60-	99.70-
Nickel	15.50+	35.40-	25.40-
Magnesium	10.00+	4.60-	5.00+
Calcium	113.30+	18.80-	73.30+

* - indicates percent removal
+ + indicates percent addition

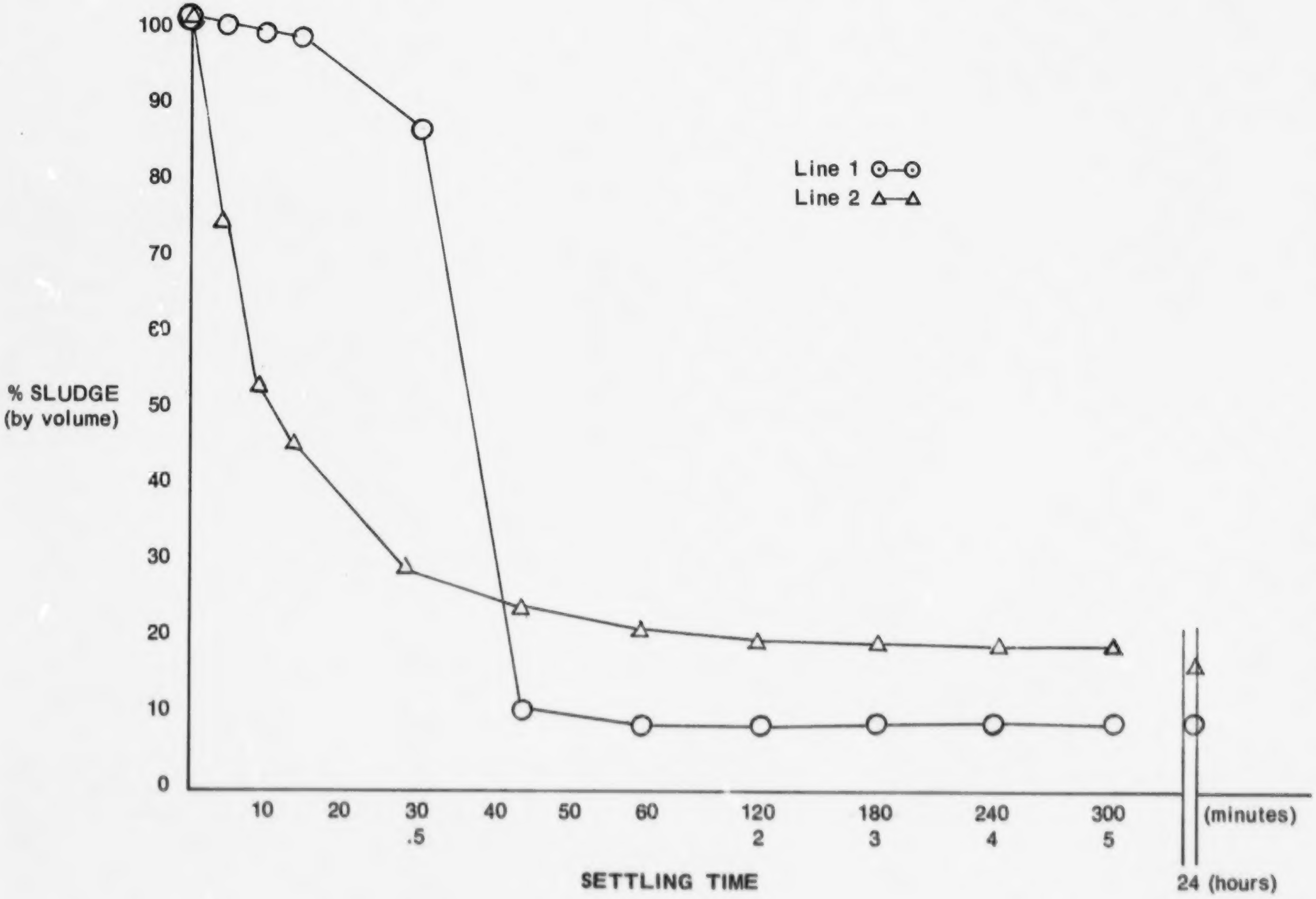


Figure 1.
SLUDGE SETTLING BEHAVIOR

WILL SCARLET WATER TREATMENT PLANT RESEARCH REPORT NO. 13

DATE November 23, 1973

I. DESCRIPTION OF RESEARCH STAGE

A. According to the research schedule, rotary hydrated lime was used on the treatment agent on both treatment lines at a counterpoise weight of six pounds per belt-foot. Sludge was recirculated to the rapid-mixers, each to its respective side at a rate of 88.3 GPM on line #1 and 94.8 GPM on line #2. The flow pattern was series (100/100) and the treatment line effluent pH's that were attempted were pH 6.0 on line #1 and pH 7.0 on line #2.

B. For the research period, November 13-14, 1973, (39 hours of operation) the following summary is submitted:

TABLE I TREATMENT DISCHARGE VOLUMES*

Units	Sludge volume	Water influent	Sludge/water ratio
	Line 1		
Gallons	436,080	4,550,400	.095
Liters	1,651,783	17,236,005	
	Line 2		
Gallons	393,420	3,033,600	.129
Liters	1,490,196	11,490,670	
	Total		
Gallons	829,500	7,584,000	.109
Liters	3,141,980	28,726,675	

*pH desired: Line 1, 6.0; Line 2, 7.0. Actual pH: Line 1, 6.1, Line 2, 7.1; Influent, 2.6

TABLE 2 TREATMENT REQUIREMENT SUMMARY

	Line 1	Line 2
Alkalinity added (mg/l as $CaCO_3$)	6.00	8.00
Sludge volume (% of initial volume after 24 hours)	25.00	25.00
Treatment required (lb chemical/1000 gal influent)	17.59	29.83

TABLE 3 TREATMENT COST SUMMARY

Line	Cost Unit*	Total Weight+	Water Influent#	¢/vol §	¢/vol/ppm‡‡
1	1.26	80,046	4,550,400	22.7	3.7
2	1.26	90,486	3,033,600	37.6	6.2
Subtotal:	--	170,532	7,584,000	--	--
Total (chemical only):		---	---	28.3	4.6
Total (operating):		---	---	34.2	5.6

* ¢/lb of chemical

+ lb of chemical

‡‡ Gal of water treated

§ Cost, ¢/1000 gal of plant influent

# Cost, ¢/1000 gal of plant influent/1000 ppm acidity as $CaCO_3$ (b.p. to pH 8.3)

2. RESULTS OF TREATMENT PLANT ANALYSIS

Refer to Table 4

3. RESULTS OF METAL ANALYSIS FROM THE CENTRAL LABORATORY

Refer to Table 5

4. PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

Refer to Table 6

5. PROPERTIES OF PLANT SLUDGE

A. Sludge settling behavior

Refer to Figure 1

B. Solids content (%) of sludges

Line 1	(pH 6.2)	4.44%
Line 2	(pH 7.0)	4.82%

TABLE 4 RESULTS OF TREATMENT PLANT ANALYSES

Parameter	Plant Influent			Line 1			Line 2		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Temperature (C)	11.8	15.4	13.9	11.9	15.5	13.9	11.9	15.5	13.9
pH	2.5	2.6	2.6	5.4	6.6	6.0	6.5	7.1	6.9
Acidity, b.p. to pH 8.3*	5400	6900	6100	75	100	92	53	100	76
Acidity, cold to 7.3, H_2O_2*	4400	5600	5200	24	57	37	10	30	17
Alkalinity*	0	0	0	5.0	9.3	6.1	5.4	12	8.2
Specific conductivity+	6400	9100	7900	4700	6600	5700	4900	6400	5700
Iron, ferrous, ppm	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Iron, ferric, ppm	840	1030	950	0.6	1.6	1.0	0.3	2.4	1.0
Sulfate, SO_4 ppm	6700	6900	6800	5800	6000	5900	5900	6100	6000

* ppm as $CaCO_3$

+ umhos/cm at 25C

TABLE 5 METAL ANALYSIS* (A.A. SPECTROPHOTOMETRY FROM CENTRAL LAB.)

Collection site	pH	Cu	Cr	Pb	Mn	Fe	Zn	Al	Ni	Mg	Ca
☐ Plant influent	2.5	0.20	0.12	0.43	220	970	19.4	355	5.88	600	225
☐ Line 1	6.0	0.04	0.07	0.43	150	1.90	2.46	1.55	4.90	550	410
☐ Line 2	7.0	0.04	0.05	0.43	105	1.95	0.30	1.25	3.56	550	390

*Results in mg/l; pH in standard units

TABLE 6 PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

PARAMETER	Percent removal/addition	
	Line 1	Line 2
Acidity	99.30-*	99.70-
Conductivity	27.90-	27.90-
Sulfate	13.30-	11.80-
Copper	80.00-	80.00-
Chromium	41.70-	58.40-
Lead	.00-	.00-
Manganese	31.90-	52.30-
Iron ABS	99.90-	99.80-
Zinc	87.40-	98.50-
Aluminum	99.60-	99.70-
Nickel	16.70-	39.50-
Magnesium	8.40-	8.40-
Calcium	82.20+	73.30++

* - indicates percent removal

+ + indicates percent addition

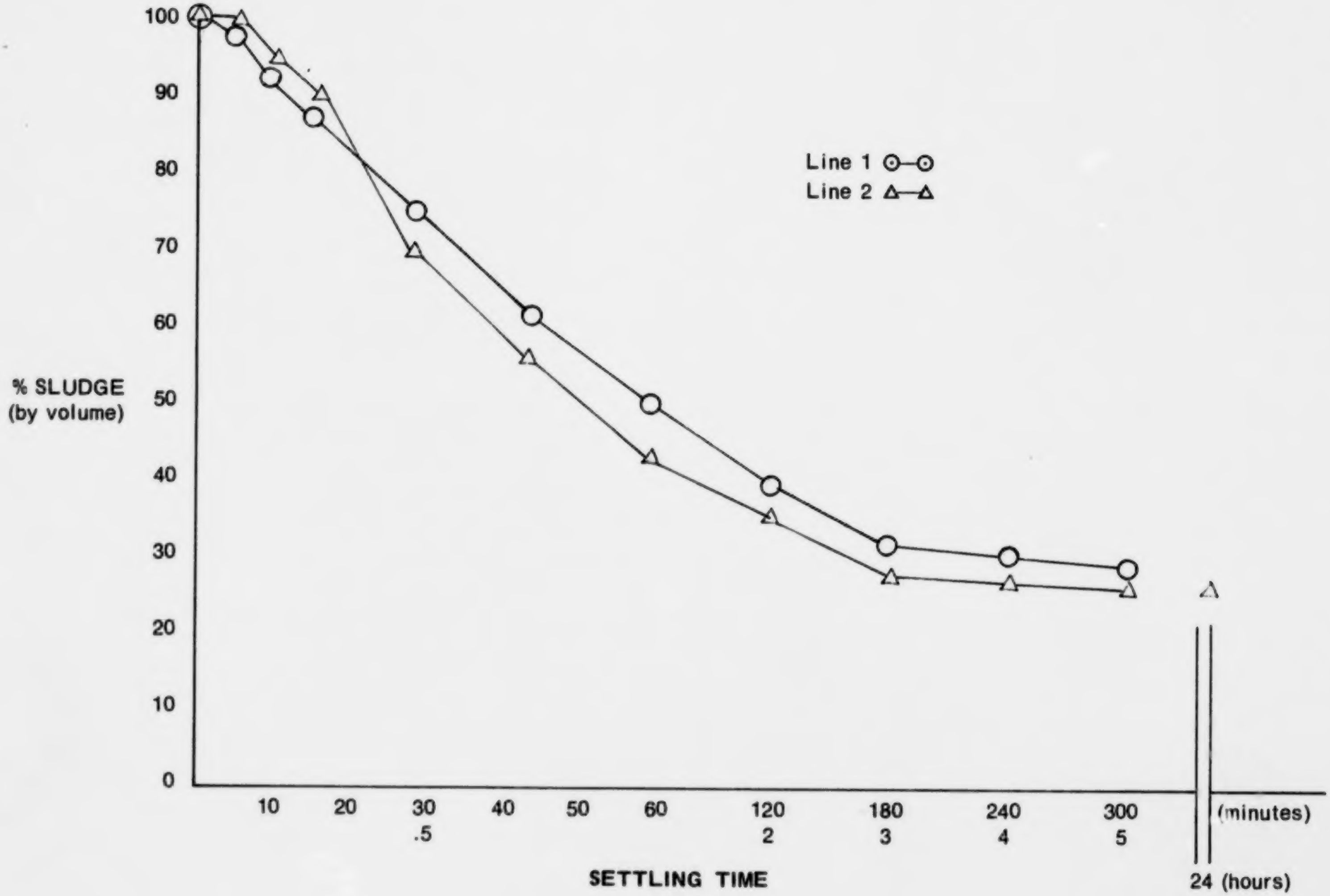


Figure 1.
SLUDGE SETTLING BEHAVIOR

WILL SCARLET WATER TREATMENT PLANT RESEARCH REPORT NO. 14

DATE November 23, 1973

I. DESCRIPTION OF RESEARCH STAGE

A. According to the research schedule, rotary hydrated lime was used on the treatment agent on both treatment lines at a counterpoise weight of six pounds per belt-foot. Sludge was recirculated to the rapid-mixers, each to its respective side at a rate of 88.3 GPM on line #1 and 94.8 GPM on line #2. The flow pattern was series (100/100) and the treatment line effluent pH's that were attempted were pH 6.0 on line #1 and pH 7.0 on line #2.

B. For the research period, November 15, 1973, (15.0 hours of operation) the following summary is submitted:

TABLE I TREATMENT DISCHARGE VOLUMES*

Units	Sludge volume	Water influent	Sludge/water ratio
Line 1			
Gallons	165,600	1,929,600	.085
Liters	627,259	7,308,938	
Line 2			
Gallons	149,400	950,400	.157
Liters	565,897	3,599,925	
Total			
Gallons	315,000	2,880,000	
Liters	1,193,157	10,908,864	

*pH desired: Line 1, 6.0; Line 2, 7.0. Actual pH: Line 1, 6.0; Line 2, 6.9; influent, 2.5

TABLE 2 TREATMENT REQUIREMENT SUMMARY

	Line 1	Line 2
Alkalinity added (mg/l as $CaCO_3$)	5.00	7.00
Sludge volume (% of initial volume after 24 hours)	21.00	18.00
Treatment required (lb chemical/1000 gal influent)	21.62	28.56

TABLE 3 TREATMENT COST SUMMARY

Line	Cost Unit*	Total Weight+	Water Influent#	¢/vol §	¢/vol/ppm‡‡
1	1.26	41,712	1,929,600	27.2	4.9
2	1.26	27,132	950,400	36.0	6.4
Subtotal:	--	68,844	2,880,000	--	---
Total (chemical only):		---	---	30.1	5.4
Total (operating):		---	---	36.0	6.4

* ¢/lb of chemical

+ lb of chemical

‡‡ Gal of water treated

§ Cost, ¢/1000 gal of plant influent

# Cost, ¢/1000 gal of plant influent/1000 ppm acidity as $CaCO_3$ (b.p. to pH 8.3)

2. RESULTS OF TREATMENT PLANT ANALYSIS

   Refer to Table 4

3. RESULTS OF METAL ANALYSIS FROM THE CENTRAL LABORATORY

   Refer to Table 5

4. PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

   Refer to Table 6

5. PROPERTIES OF PLANT SLUDGE

   A. Sludge settling behavior

      Refer to Figure 1

   B. Solids content (%) of sludges

Line 1	(pH 6.0)	5.25%
Line 2	(pH 7.0)	5.99%

TABLE 4 RESULTS OF TREATMENT PLANT ANALYSES

Parameter	Plant Influent			Line 1			Line 2		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Temperature (C)	13.2	15.4	14.5	13.4	15.3	14.5	13.4	15.3	14.5
pH	2.5	2.5	2.5	5.9	6.5	6.1	6.7	7.1	6.9
Acidity, b.p. to pH 8.3*	5300	5700	5600	45	110	86	54	79	63
Acidity, cold to 7.3, H_2O_2*	5300	5600	5500	19	67	37	11	26	18
Alkalinity*	0	0	0	3.0	6.5	5.0	6.0	7.0	6.5
Specific conductivity+	7100	8600	8100	5200	6500	5900	5000	6200	5700
Iron, ferrous, ppm	36	43	40	0.1	0.1	0.1	0.1	0.1	0.1
Iron, ferric, ppm	940	990	970	0.8	1.6	1.2	0.8	1.2	1.1
Sulfate, SO_4 ppm	7100	7300	7200	6700	6900	6800	6700	6900	6900

* ppm as $CaCO_3$

+ umhos/cm at 25C

TABLE 5 METAL ANALYSIS* (A.A. SPECTROPHOTOMETRY FROM CENTRAL LAB.)

Collection site	pH	Cu	Cr	Pb	Mn	Fe	Zn	Al	Ni	Mg	Ca
☐ Plant influent	2.5	0.25	0.16	0.43	250	1,050	18.7	395	6.40	600	235
☐ Line 1	6.0	0.03	0.05	0.50	135	2.30	4.18	1.70	4.58	600	375
☐ Line 2	7.0	0.03	0.04	0.43	110	1.60	0.22	0.95	3.40	575	335

*Results in mg/l; pH in standard units

TABLE 6 PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

PARAMETER	Percent removal/addition	
	Line 1	Line 2
Acidity	99.40-*	99.70-
Conductivity	27.20-	29.70-
Sulfate	5.60-	4.20-
Copper	88.00-	88.00-
Chromium	68.80-	75.00-
Lead	16.20+⁺	.00-
Manganese	46.00-	56.00-
Iron ABS	99.80-	99.90-
Zinc	77.70-	98.90-
Aluminum	99.60-	99.80-
Nickel	28.50-	46.90-
Magnesium	.00-	4.20-
Calcium	59.50+	42.50+

* - indicates percent removal
+ + indicates percent addition

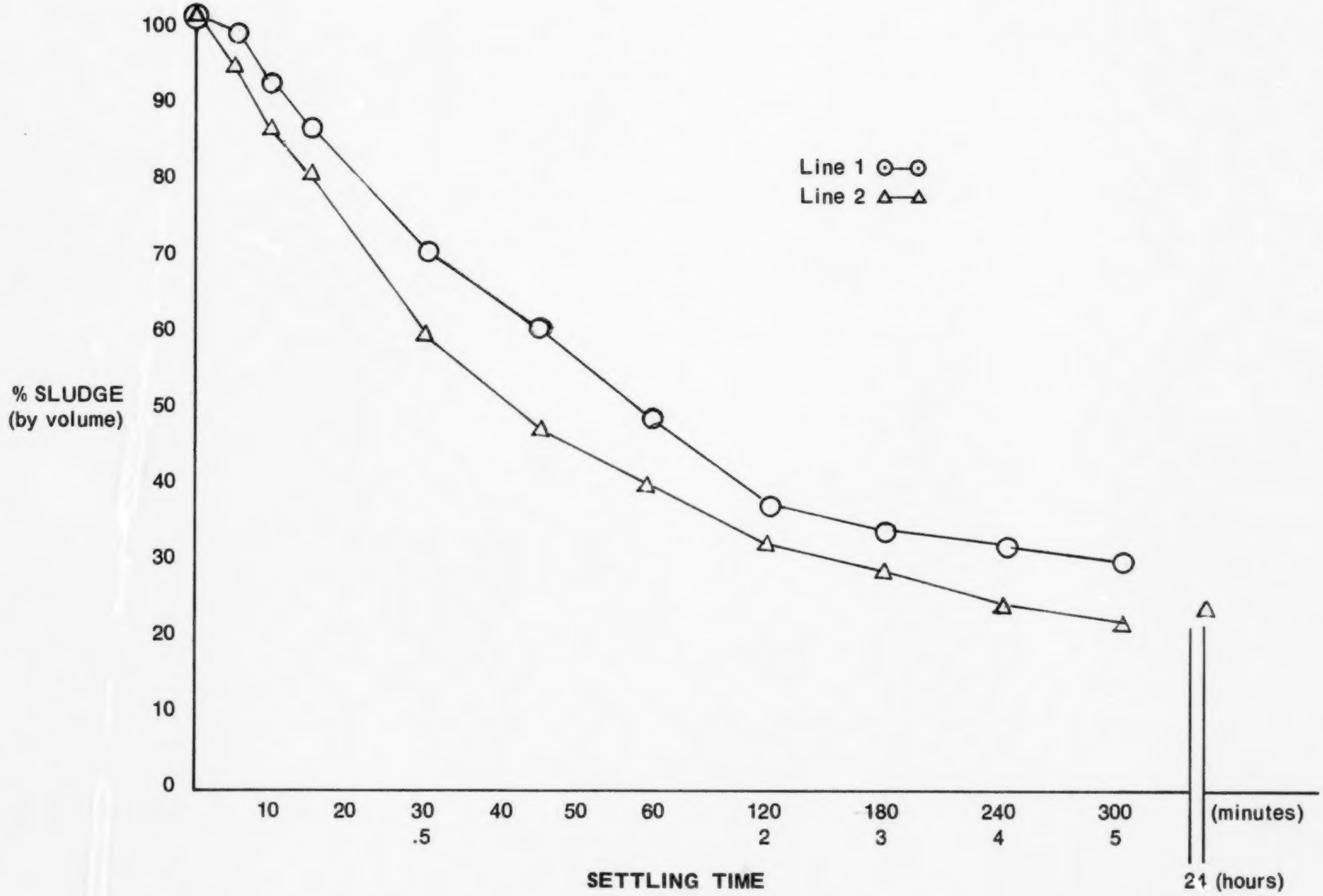


Figure 1.
SLUDGE SETTLING BEHAVIOR

WILL SCARLET WATER TREATMENT PLANT RESEARCH REPORT NO. 15

DATE December 4, 1973

I. DESCRIPTION OF RESEARCH STAGE

A. According to the research schedule, rotary hydrated lime was used as the neutralizing agent on both treatment lines at counterpoise weight of six pounds per belt-foot. There was no sludge recirculation and the flow pattern was parallel (75/75). An effort was made to maintain pH 6.0 on line #1 and pH 7.0 on line #2.

B. For the research period, November 19-20, 1973, (23.1 hours of operation) the following summary is submitted:

TABLE 1 TREATMENT DISCHARGE VOLUMES*

Units	Total Water Influent	Line 1 Water Influent	Line 2 Water Influent
Gallons	4,435,200	2,971,584	1,463,616
Liters	16,799,650	11,255,765	5,543,884

*pH desired: Line 1, 6.0; Line 2, 7.0. Actual pH; Line 1, 6.1
Line 2, 7.1
influent, 2.5

TABLE 2 TREATMENT REQUIREMENT SUMMARY

Item	Line 1	Line 2
Alkalinity added (mg/l as $CaCO_3$)	6.00	7.00
Sludge volume (% of initial volume after 24 hours)	25.00	20.00
Treatment required (lb chemical/1000 gal influent)	21.40	27.98

TABLE 3 TREATMENT COST SUMMARY

Line	Cost Unit*	Total Weight+	Water Influent#	¢/vol§	¢/vol/ppm‡‡
1	1.26	63,594	2,971,584	27.0	8.7
2	1.26	40,948	1,463,616	35.3	11.4
Subtotal:	---	104,542	4,435,200		
Total (chemical only):		---	---	23.6	7.6
Total (operating):		---	---	35.6	11.5

* ¢/lb of chemical

+ lb of chemical

# Gal of water treated

§ Cost, ¢/1000 gal of plant influent

‡‡ Cost, ¢/1000 gal of plant influent/1000 ppm acidity as $CaCO_3$ (b.p. to pH 8.3)

2. RESULTS OF TREATMENT PLANT ANALYSIS

Refer to Table 4

3. RESULTS OF METAL ANALYSIS FROM THE CENTRAL LABORATORY

Refer to Table 5

4. PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

Refer to Table 6

5. PROPERTIES OF PLANT SLUDGE

A. Sludge settling behavior

Refer to Figure 1

B. Solids content (%) of sludges

Line 1	(pH 6.0)	4.84%
Line 2	(pH 7.0)	6.71%

TABLE 4 RESULTS OF TREATMENT PLANT ANALYSES

Parameter	Plant Influent			Line 1			Line 2		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Temperature (C)	20.0	22.3	21.5	19.8	22.0	21.0	19.9	22.3	21.2
pH	2.58	2.64	2.61	4.48	4.48	4.65	5.72	5.98	5.78
Acidity, b.p. to pH 8.3*	2828	3267	3100	326.9	541.5	376.6	126.4	207.3	177.7
Acidity, cold to 7.3, H_2O_2*	2533	2816	2648	206.3	351.2	259.2	56.7	129.4	106.9
Alkalinity*	0	0	0	-16.5	8.6	0.6	75.5	110.9	92.9
Specific conductance+	4033	5064	4628	3669	5052	4486	3738	5153	4588
Iron, ferrous, ppm	8.65	10.20	9.29	0.1	2.17	0.86	0.1	2.00	0.82
Iron, ferric, ppm	225.8	370.6	328.7	0	3.07	1.55	0	2.75	1.33
Sulfate, SO_4 ppm	4500	4800	4630	3910	4500	4203	3750	4500	4238

* ppm as $CaCO_3$

+ umhos/cm at 25C

TABLE 5 METAL ANALYSIS* (A.A. SPECTROPHOTOMETRY FROM CENTRAL LAB.)

Collection site	pH	Cu	Cr	Pb	Mn	Fe	Zn	Al	Ni	Mg	Ca
☐ Plant Influent	2.5	0.35	0.12	0.36	235	985	21.6	395	6.17	600	225
☐ Line 1	6.0	0.08	0.07	0.43	155	1.45	8.60	37.9	5.48	600	330
☐ Line 2	7.0	0.03	0.05	0.50	90.0	1.25	0.18	0.75	3.34	600	320

*Results in mg/l; pH in standard units

TABLE 6 PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

PARAMETER	Percent removal/addition	
	Line 1	Line 2
Acidity	99.40-*	99.60-
Conductivity	28.60-	28.60-
Sulfate	8.50-	12.70-
Copper	77.20-	91.50-
Chromium	41.70-	58.40-
Lead	19.40+	38.80++
Manganese	34.10-	61.80-
Iron ABS	99.90-	99.90-
Zinc	60.20-	99.20-
Aluminum	90.50-	99.90-
Nickel	91.20-	94.60-
Magnesium	.00-	.00-
Calcium	46.60+	42.20+

* - indicates percent removal

+ + indicates percent addition

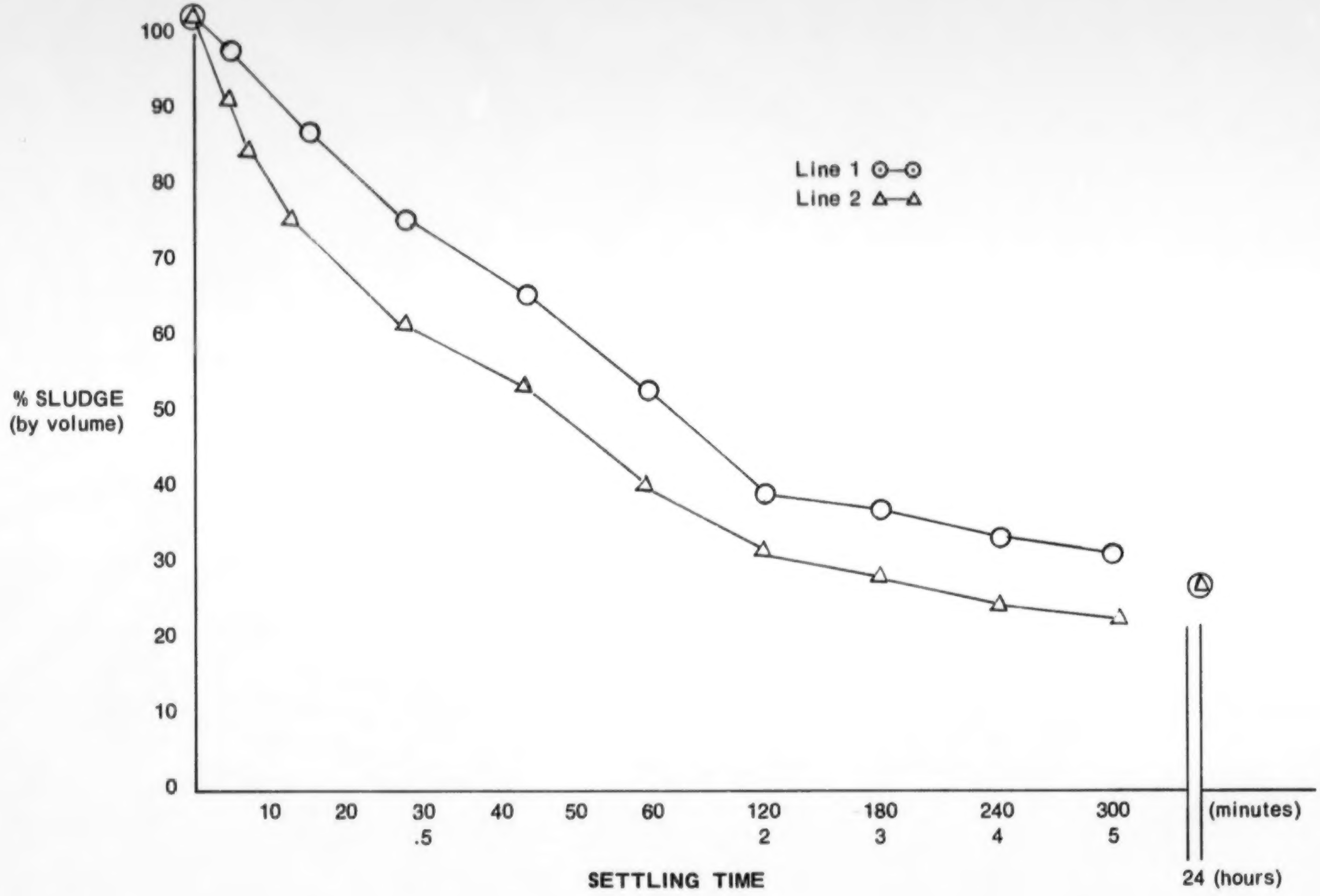


Figure 1.
SLUDGE SETTLING BEHAVIOR

WILL SCARLET WATER TREATMENT PLANT RESEARCH REPORT NO. 16

DATE March 6, 1974

I. DESCRIPTION OF RESEARCH STAGE

A. According to the research schedule, rotary hydrated lime was used on No. 2 treatment line, while limestone was used on the No. 1 treatment line, each neutralizing chemical at six and ten pounds per belt-foot counterpoise weight, respectively. The flow pattern was series at 50% of total flow and sludge was recirculated to the rapid-mix vessels at a rate of 203 GPM on line #1 and 167 GPM on line #2. An effort was made to maintain pH 3.0 - 3.5 on line #1 and pH 7.0 on line #2 effluent.

B. For the research period January 18-19, 1974, (32.0 hours of operation) the following summary is submitted:

TABLE I TREATMENT DISCHARGE VOLUMES*

Units	Sludge volume	Water influent	Sludge/water ratio
	Line 1		
Gallons	289,760	2,799,360	.103
Liters	1,097,552	10,603,415	
	Line 2		
Gallons	320,640	2,799,360	.114
Liters	1,214,520	10,603,415	
	Total		
Gallons	610,400	2,799,360	.218
Liters	2,312,073	10,603,415	

*pH desired: Line 1, 3.5; Line 2, 7.0. Actual pH: Line 1, 3.7; Line 2, 7.8; influent, 3.0

TABLE 2 TREATMENT REQUIREMENT SUMMARY

	Line 1	Line 2
Alkalinity added (mg/l as $CaCO_3$)	0.00	34.00
Sludge volume (% of initial volume after 24 hours)	2.00	8.00
Treatment required (lb chemical/1000 gal influent)	4.51	6.26

TABLE 3 TREATMENT COST SUMMARY

Line	Cost Unit*	Total Weight+	Water Influent#	¢/vol §	¢/vol/ppm‡‡
1	0.46	12,650	2,799,360	2.1	1.2
2	1.26	17,526	2,799,360	7.9	4.6
Subtotal:	--	30,176	2,799,360	-	-
Total (chemical only):		---	---	10.0	5.8
Total (operating):		---	---	22.3	13.1

* ¢/lb of chemical

+ lb of chemical

‡‡ Gal of water treated

§ Cost, ¢/1000 gal of plant influent

# Cost, ¢/1000 gal of plant influent/1000 ppm acidity as $CaCO_3$ (b.p. to pH 8.3)

2. RESULTS OF TREATMENT PLANT ANALYSIS

   Refer to Table 4

3. RESULTS OF METAL ANALYSIS FROM THE CENTRAL LABORATORY

   Refer to Table 5

4. PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

   Refer to Table 6

5. PROPERTIES OF PLANT SLUDGE

   A. Sludge settling behavior

      Refer to Figure 1

   B. Solids content (%) of sludges

Line 1	(pH 3.8)	4.01%
Line 2	(pH 7.0)	2.72%

TABLE 4 RESULTS OF TREATMENT PLANT ANALYSES

Parameter	Plant Influent			Line 1			Line 2		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Temperature (C)	8.2	1.24	10.0	8.4	12.1	10.0	8.4	12.1	10.0
pH	2.9	3.0	3.0	3.6	3.9	3.7	6.8	9.2	7.8
Acidity, b.p. to pH 8.3*	1300	2200	1700	940	1600	1200	0	79	19
Acidity, cold to 7.3, H_2O_2*	990	1800	1300	640	1100	850	0	48	10
Alkalinity*	0	0	0	0	0	0	24	43	34
Specific conductivity+	2400	3700	3300	2700	3700	3300	2800	4000	3500
Iron, ferrous, ppm	20	64	44	=0.1	0.1	0.1	0.1	0.1	0.1
Iron, ferric, ppm	120	260	180	44	85	63	0.5	1.7	0.9
Sulfate, SO_4 ppm	2200	2300	2300	2300	2500	2400	2500	2600	2500

* ppm as $CaCO_3$

+ umhos/cm at 25C

TABLE 5 METAL ANALYSIS* (A.A. SPECTROPHOTOMETRY FROM CENTRAL LAB.)

Collection site	pH	Cu	Cr	Pb	Mn	Fe	Zn	Al	Ni	Mg	Ca
☐ Plant influent	3.0	0.15	0.06	0.14	52.5	223	5.34	90.0	2.30	89.5	70.0
☐ Line 1	3.7	0.16	0.07	0.27	45.0	87.0	6.20	87.5	2.60	90.5	110
☐ Line 2	7.7	0.03	0.06	0.27	25.0	3.75	0.47	1.80	2.50	84.0	200

*Results in mg/l; pH in standard units

TABLE 6 PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

PARAMETER	Percent removal/addition		
	Line 1	Line 2	Total
Acidity	43.70-*	98.90-	99.30-
Conductivity	.00-	6.00+	6.00++
Sulfate	4.30+	4.10+	8.60+
Copper	6.60+	81.30-	80.00-
Chromium	16.60+	14.30-	.00-
Lead	92.80+	.00-	92.80+
Manganese	14.30-	44.50-	52.40-
Iron ABS	61.00-	95.70-	98.40-
Zinc	16.10+	92.50-	91.20-
Aluminum	2.80-	98.00-	98.00-
Nickel	13.00+	3.90-	8.60+
Magnesium	1.10+	7.20-	6.20-
Calcium	57.10+	81.80+	185.70+

* - indicates percent removal
+ + indicates percent addition

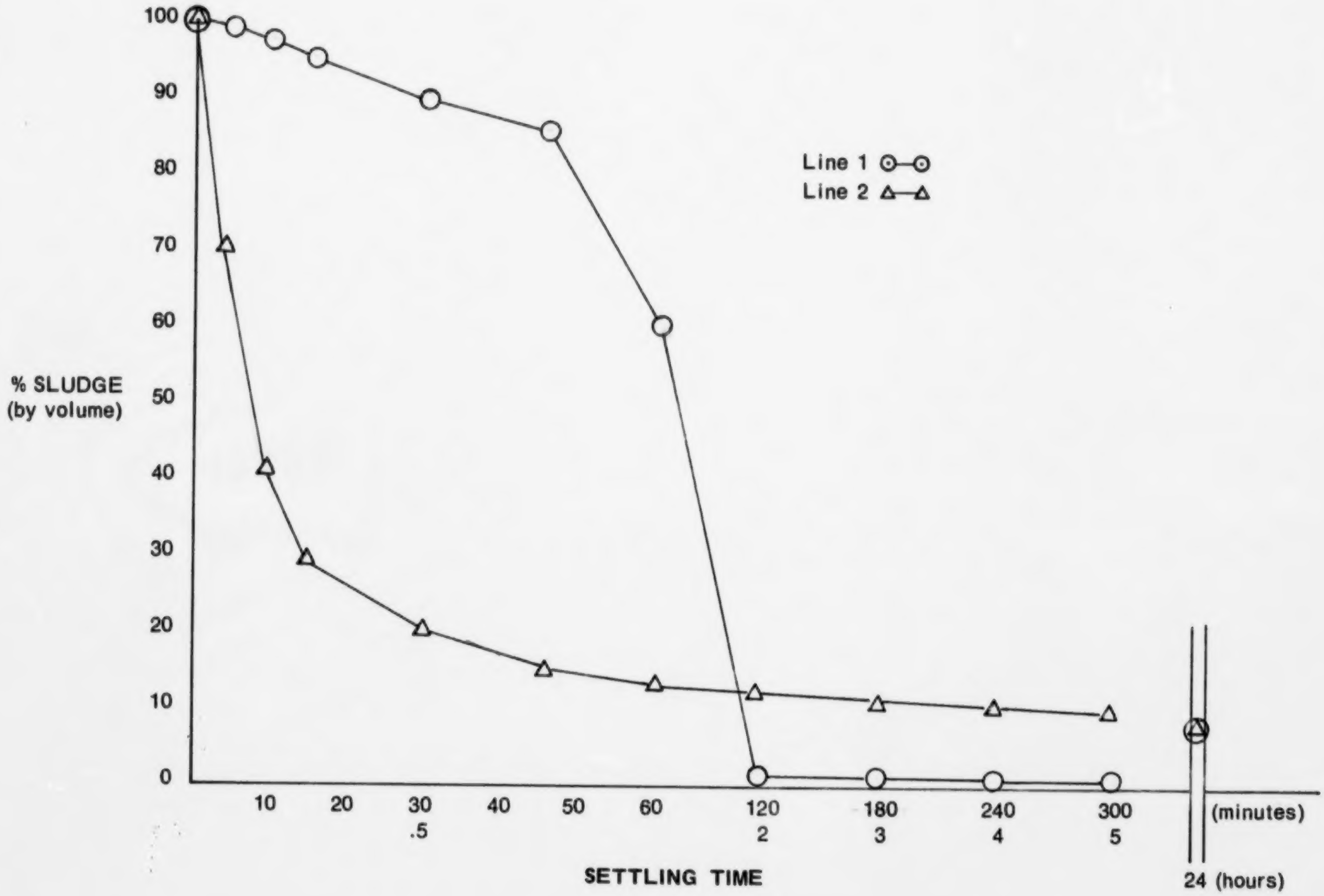


Figure 1.
SLUDGE SETTLING BEHAVIOR

WILL SCARLET WATER TREATMENT PLANT RESEARCH REPORT NO. 17

DATE March 7, 1974

I. DESCRIPTION OF RESEARCH STAGE

A. According to the revised research schedule, limestone was used on the No. I treatment line, while rotary hydrated lime was used as the neutralizing agent on the No. 2 line; each set at ten pounds and six pounds per belt-foot, respectively. The flow pattern was series at 100% of total flow, and sludge was recirculated to the rapid-mix vessels at a rate of 175 GPM on line No. I and 156 GPM on line No. 2. An effort was made to maintain pH 3.03 - 3.5 on line No. I and pH 7.0 on line No. 2.

B. For the research period January 30-31, 1974, (38.0 hours of operation) the following summary is submitted:

TABLE I TREATMENT DISCHARGE VOLUMES*

Units	Sludge volume	Water influent	Sludge/water ratio
	Line I		
Gallons	504,000	6,726,000	.074
Liters	1,909,061	25,476,742	
	Line 2		
Gallons	449,280	6,726,000	.066
Liters	1,701,782	25,476,742	
	Total		
Gallons	953,280	6,726,000	.141
Liters	3,610,833	25,476,742	

*pH desired: Line I, 3.5, Line 2, 7.0. Actual pH: Line I, 3.7; Line 2, 7.1; influent, 3.0

TABLE 2 TREATMENT REQUIREMENT SUMMARY

	Line 1	Line 2
Alkalinity added (mg/l as $CaCO_3$)	0.00	35.00
Sludge volume (% of initial volume after 24 hours)	1.00	8.00
Treatment required (lb chemical/1000 gal influent)	4.50	5.02

TABLE 3 TREATMENT COST SUMMARY

Line	Cost Unit*	Total Weight+	Water Influent#	¢/vol §	¢/vol/con‡‡
1	0.46	30,280	6,726,000	2.1	1.3
2	1.26	33,810	6,726,000	6.3	3.9
Subtotal:	--	64,090	6,726,000	-	-
Total (chemical only):		---	---	8.4	5.2
Total (operating):		---	---	14.3	8.9

* ¢/lb of chemical
+ lb of chemical
‡‡ Gal of water treated
§ Cost, ¢/1000 gal of plant influent
# Cost, ¢/1000 gal of plant influent/1000 ppm acidity as $CaCO_3$ (b.p. to pH 8.3)

2. RESULTS OF TREATMENT PLANT ANALYSIS

   Refer to Table 4

3. RESULTS OF METAL ANALYSIS FROM THE CENTRAL LABORATORY

   Refer to Table 5

4. PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

   Refer to Table 6

5. PROPERTIES OF PLANT SLUDGE

   A. Sludge settling behavior

      Refer to Figure 1

   B. Solids content (%) of sludges

Line 1	(pH 3.0)	4.75%
Line 2	(pH 7.0)	5.20%

TABLE 4 RESULTS OF TREATMENT PLANT ANALYSES

Parameter	Plant Influent			Line 1			Line 2		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Temperature (C)	11.0	12.4	11.5	11.1	12.3	11.5	11.1	12.3	11.5
pH	2.9	3.0	3.0	3.4	3.9	3.7	6.4	7.2	6.9
Acidity, b.p. to pH 8.3*	1400	1700	1600	890	1300	1100	26	51	37
Acidity, cold to 7.3, H_2O_2*	1000	1300	1200	630	770	700	30	36	33
Alkalinity*	0	0	0	0	0	0	23	40	35
Specific conductivity+	2300	3300	2900	2200	3300	2900	2400	3200	2900
Iron, ferrous, ppm	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Iron, ferric, ppm	150	190	180	12	27	14	0.6	0.8	0.7
Sulfate, SO_4 ppm	2700	2800	2800	2800	2900	2900	3000	3000	3000

* ppm as $CaCO_3$

+ umhos/cm at 25C

TABLE 5 METAL ANALYSIS* (A.A. SPECTROPHOTOMETRY FROM CENTRAL LAB.)

Collection site	pH	Cu	Cr	Pb	Mn	Fe	Zn	Al	Ni	Mg	Ca
☐ Plant influent	2.9	0.17	0.15	0.27	47.5	182	5.70	95.0	2.30	82.5	70
☐ Line 1	3.5	0.14	0.06	0.27	45.0	30.2	5.09	85.0	2.90	83.0	110
☐ Line 2	7.0	0.04	0.00	0.41	40.0	1.75	0.34	1.00	2.80	81.5	170

*Results in mg/l; pH in standard units

TABLE 6 PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

PARAMETER	Percent removal/addition Line 1	 Line 2	 Total
Acidity	41.70-*	95.30-	97.30-
Conductivity	.00-	.00-	.00-
Sulfate	3.50+	3.40+	7.10+
Copper	17.70-	71.50-	76.50-
Chromium	60.00-	100.00-	100.00-
Lead	.00-	51.80+	51.80+
Manganese	5.30-	11.20-	15.80-
Iron ABS	83.50-	94.30-	99.10-
Zinc	10.80-	93.40-	94.10-
Aluminum	10.60-	98.90-	99.00-
Nickel	26.00+	3.50-	21.70+
Magnesium	.60+	1.90-	1.30-
Calcium	57.10+	54.50+	142.80+

* - Indicates percent removal

+ + Indicates percent addition

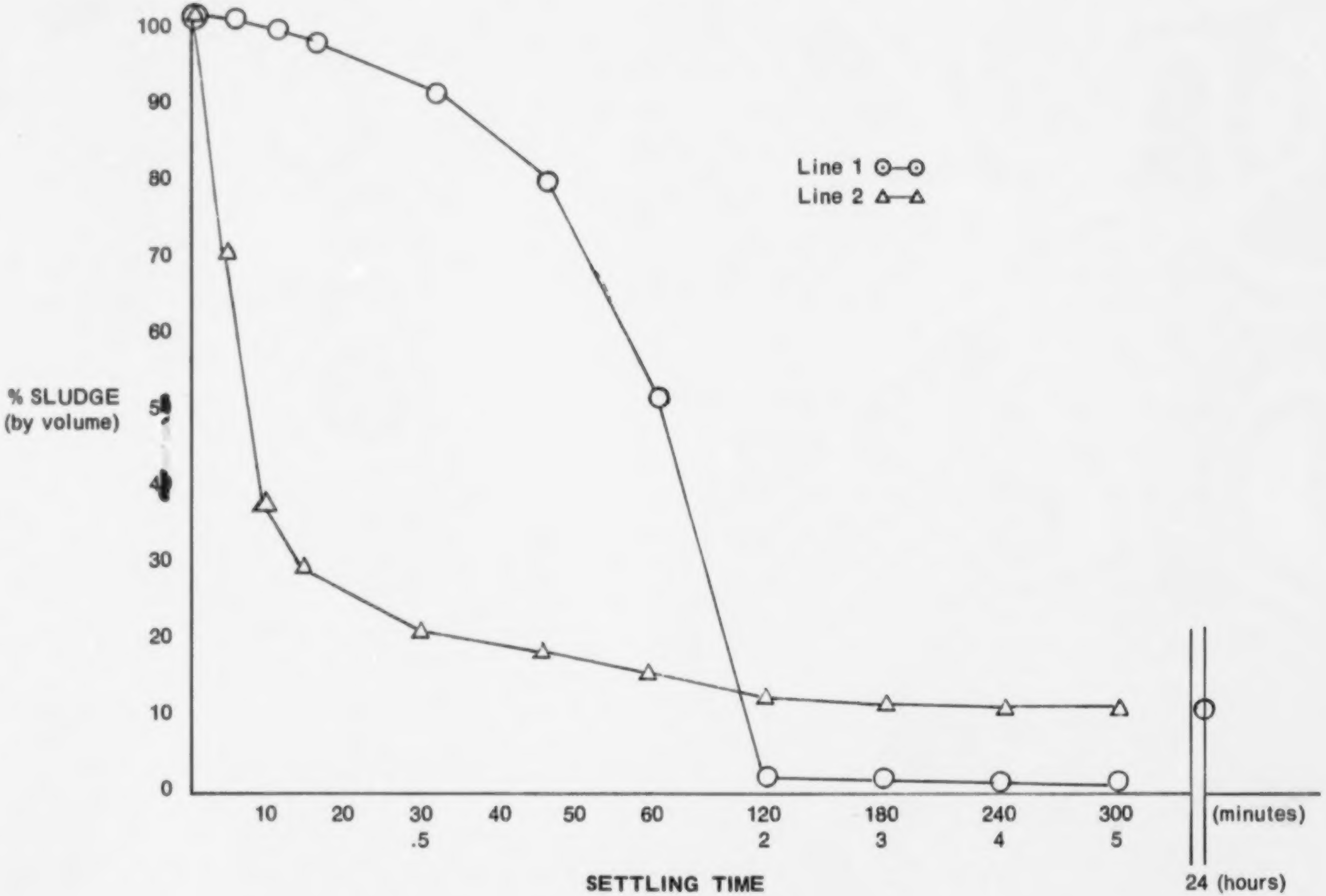


Figure 1.
SLUDGE SETTLING BEHAVIOR

WILL SCARLET WATER TREATMENT PLANT RESEARCH REPORT NO. 18

DATE March 7, 1974

I. DESCRIPTION OF RESEARCH STAGE

A. According to the revised research schedule, limestone was used on the No. 1 treatment line, while rotary hydrated lime was used as the neutralizing agent on the No. 2 line, each set at ten and six pounds per belt-foot, respectively. The flow pattern was series at 100% of total flow, and sludge was recirculated to the No. 1 rapid-mix vessel only, at a rate of 175 GPM. An effort was made to maintain line No. 1 effluent pH at 3.0 to 3.5 and line No. 2 effluent pH at 7.0.

B. For the research period February 1, 1974, (22.0 hours of plant operation) the following summary is submitted:

TABLE 1 TREATMENT DISCHARGE VOLUMES*

Units	Sludge volume	Water influent	Sludge/water ratio
	Line 1		
Gallons	231,000	3,894,000	.059
Liters	874,981	14,749,693	
	Line 2		
Gallons	0	3,894,000	.000
Liters	0	14,749,693	
	Total		
Gallons	231,000	3,894,000	.059
Liters	874,981	14,749,693	

*pH desired: Line 1, 3.5; Line 2, 7.0. Actual pH: Line 1, 3.2; Line 2, 7.2; influent, 2.9

TABLE 2 TREATMENT REQUIREMENT SUMMARY

	Line 1	Line 2
Alkalinity added (mg/l as $CaCO_3$)	0.00	27.00
Sludge volume (% of initial volume after 24 hours)	1.00	14.00
Treatment required (lb chemical/1000 gal influent)	4.20	8.31

TABLE 3 TREATMENT COST SUMMARY

Line	Cost Unit*	Total Weight+	Water Influent#	¢/vol §	¢/vol/ppm‡‡
1	0.46	16,370	3,894,000	1.9	0.9
2	1.26	32,394	3,894,000	10.5	4.8
Subtotal:	--	48,764	3,894,000	--	-
Total (chemical only):		---	---	12.4	5.7
Total (operating):		---	---	18.7	8.5

* ¢/lb of chemical

+ lb of chemical

‡‡ Gal of water treated

§ Cost, ¢/1000 gal of plant influent

# Cost, ¢/1000 gal of plant influent/1000 ppm acidity as $CaCO_3$ (b.p. to pH 8.3)

2. RESULTS OF TREATMENT PLANT ANALYSIS

   Refer to Table 4

3. RESULTS OF METAL ANALYSIS FROM THE CENTRAL LABORATORY

   Refer to Table 5

4. PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

   Refer to Table 6

5. PROPERTIES OF PLANT SLUDGE

   A. Sludge settling behavior

      Refer to Figure 1

   B. Solids content (%) of sludges

Line 1	(pH 3.5)	4.50%
Line 2	(pH 7.0)	1.60%

TABLE 4 RESULTS OF TREATMENT PLANT ANALYSES

Parameter	Plant Influent			Line 1			Line 2		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Temperature (C)	11.8	12.0	12.0	11.7	12.1	12.0	11.8	12.0	11.9
pH	2.9	2.9	2.9	3.4	3.5	3.5	7.0	7.2	7.1
Acidity, b.p. to pH 8.3*	1700	2400	2200	1200	1800	1600	15	30	27
Acidity, cold to 7.3, H_2O_2*	1600	1900	1800	960	1400	1100	20	30	25
Alkalinity*	0	0	0	0	0	0	20	36	27
Specific conductivity+	2700	3900	3400	3100	3900	3500	3100	3900	3500
Iron, ferrous, ppm	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Iron, ferric, ppm	200	340	230	25	140	67	0.5	1.2	0.9
Sulfate, SO_4 ppm	3200	3400	3300	3300	3500	3400	3400	3400	3400

* ppm as $CaCO_3$

+ umhos/cm at 25C

TABLE 5 METAL ANALYSIS* (A.A. SPECTROPHOTOMETRY FROM CENTRAL LAB.)

Collection site	pH	Cu	Cr	Pb	Mn	Fe	Zn	Al	Ni	Mg	Ca
☐ Plant influent	2.9	0.20	0.07	0.27	62.5	238	7.20	145	2.80	95.5	60.0
☐ Line 1	3.5	0.22	0.07	0.27	60.0	71.0	7.57	135	2.90	99.5	100
☐ Line 2	7.0	0.04	0.07	0.41	35.0	1.50	0.22	1.15	2.70	93.5	200

*Results in mg/l; pH in standard units

TABLE 6 PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

PARAMETER	Percent removal/addition		
	Line 1	Line 2	Total
Acidity	38.90-+	97.80-	98.70-
Conductivity	2.90+	.00-	2.90+
Sulfate	3.00+	.00-	3.00+
Copper	10.00+	81.90-	80.00-
Chromium	.00-	.00-	.00-
Lead	.00-	51.80+	51.80+
Manganese	4.00-	41.70-	44.00-
Iron ABS	70.20-	97.90-	99.40-
Zinc	5.10+	97.10-	97.00-
Aluminum	6.90-	99.20-	99.30-
Nickel	3.50+	6.90-	3.60-
Magnesium	4.10+	6.10-	2.10-
Calcium	66.60+	100.00+	233.30+

* - indicates percent removal
+ + indicates percent addition

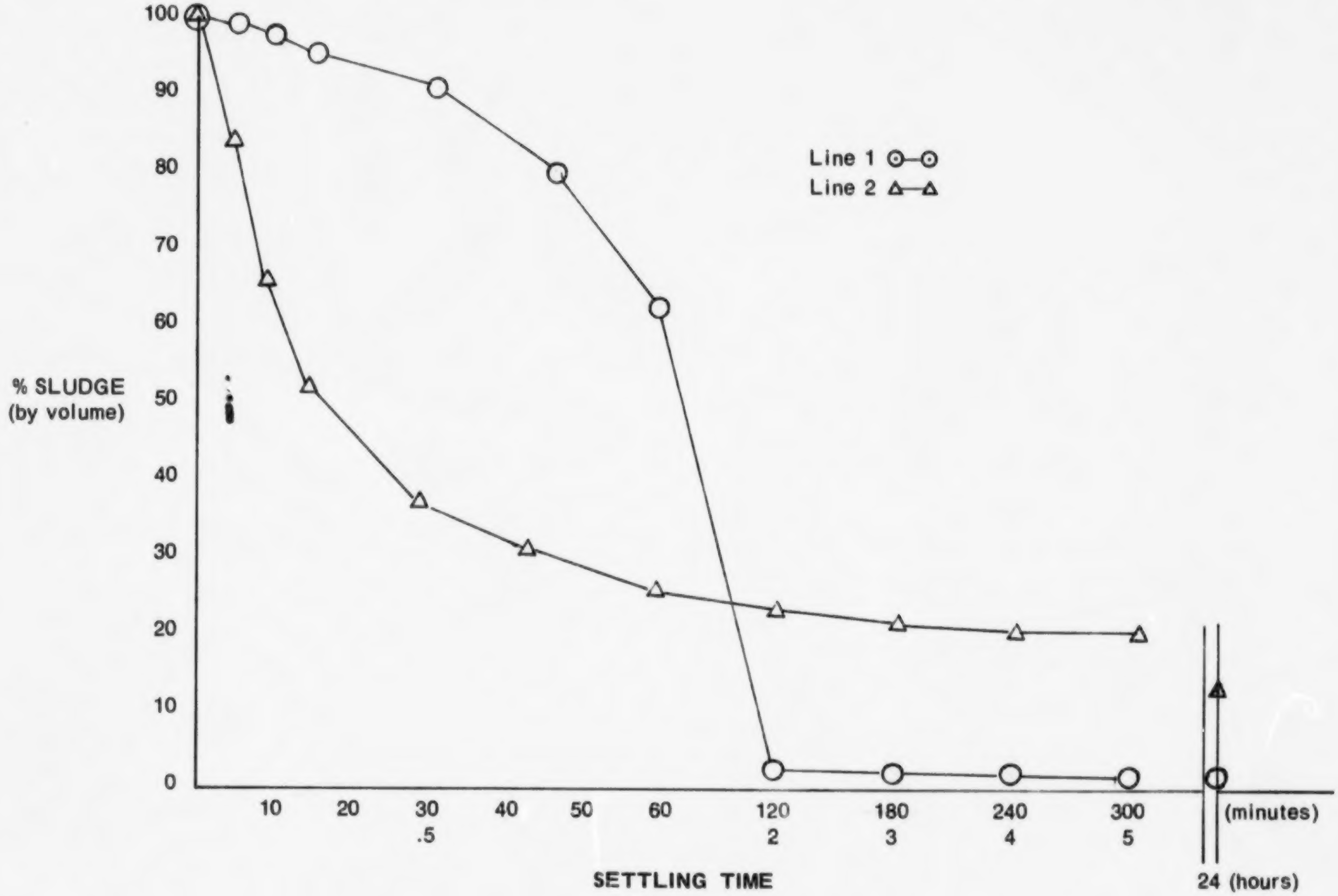


Figure 1.
SLUDGE SETTLING BEHAVIOR

WILL SCARLET WATER TREATMENT PLANT RESEARCH REPORT NO. 19

DATE March 15, 1974

I. DESCRIPTION OF RESEARCH STAGE

A. According to the revised research schedule, limestone was used on No. 1 treatment line, while rotary hydrated lime was used as the neutralizing agent on the No. 2 line, each set at ten and six pounds per belt-foot, respectively. The flow pattern was series at 100% of total flow with no sludge recirculation to the rapid-mix vessels. An effort was made to maintain line No. 1 effluent at pH 3.0 to 3.5 and line No. 2 effluent at pH 7.0.

B. For the research period, February 13-15, 1974, (42.0 hours of plant operation), the following summary is submitted:

TABLE 1 TREATMENT DISCHARGE VOLUMES*

Units	Sludge volume	Water influent	Sludge/water ratio
Line 1			
Gallons	0	7,308,000	.000
Liters	0	27,681,242	
Line 2			
Gallons	0	7,308,000	.000
Liters	0	27,681,242	
Total			
Gallons	0	7,308,000	.000
Liters	0	27,681,242	

*pH desired: Line 1, 3.5; Line 2, 7.0. Actual pH: Line 1, 3.4, Line 2, 7.3; influent, 2.8

TABLE 2 TREATMENT REQUIREMENT SUMMARY

	Line 1	Line 2
Alkalinity added (mg/l as $CaCO_3$)	0.00	46.00
Sludge volume (% of initial volume after 24 hours)	1.00	15.00
Treatment required (lb chemical/1000 gal influent)	8.99	12.43

TABLE 3 TREATMENT COST SUMMARY

Line	Cost Unit*	Total Weight+	Water Influent#	¢/vol §	¢/vol/ppm‡‡
1	0.46	65,720	7,308,000	4.1	1.4
2	1.26	90,840	7,308,000	15.7	5.2
Subtotal:	--	156,560	7,308,000	--	-
Total (chemical only):		---	---	19.8	6.6
Total (operating):		---	---	25.8	8.6

* ¢/lb of chemical

+ lb of chemical

‡‡ Gal of water treated

§ Cost, ¢/1000 gal of plant influent

# Cost, ¢/1000 gal of plant influent/1000 ppm acidity as $CaCO_3$ (b.p. to pH 8.3)

2. RESULTS OF TREATMENT PLANT ANALYSIS

   Refer to Table 4

3. RESULTS OF METAL ANALYSIS FROM THE CENTRAL LABORATORY

   Refer to Table 5

4. PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

   Refer to Table 6

5. PROPERTIES OF PLANT SLUDGE

   A. Sludge settling behavior

      Refer to Figure 1

   B. Solids content (%) of sludges

Line 1	(pH 3.4)	6.54%
Line 2	(pH 7.0)	2.62%

TABLE 4 RESULTS OF TREATMENT PLANT ANALYSES

Parameter	Plant Influent			Line 1			Line 2		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Temperature (C)	10.0	13.8	11.8	10.0	13.7	11.7	10.1	13.7	11.7
pH	2.7	2.9	2.8	3.4	3.6	3.5	6.9	7.4	7.2
Acidity, b.p. to pH 8.3*	2900	3100	3000	2300	2600	2400	4.1	53	24
Acidity, cold to 7.3, H_2O_2*	2600	2800	2700	1600	1800	1700	0	16	7.5
Alkalinity*	0	0	0	0	0	0	37	51	46
Specific conductance+	2900	4400	3900	3600	4300	4000	3200	4600	4100
Iron, ferrous, ppm	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Iron, ferric, ppm	350	380	360	35	57	45	0.5	1.2	0.9
Sulfate, SO_4 ppm	3800	3900	3850	4100	4200	4200	4200	4200	4200

* ppm as $CaCO_3$

+ umhos/cm at 25C

TABLE 5 METAL ANALYSIS* (A.A. SPECTROPHOTOMETRY FROM CENTRAL LAB.)

Collection site	pH	Cu	Cr	Pb	Mn	Fe	Zn	Al	Ni	Mg	Ca
☐ Plant influent	2.8	0.34	0.12	0.26	89.0	373	9.22	235	32.8	252	200
☐ Line 1	3.5	0.32	0.08	0.26	85.0	56.5	9.22	210	3.95	246	450
☐ Line 2	7.0	0.06	0.06	0.39	43.5	0.97	0.13	1.25	3.80	242	1030

*Results in mg/l; pH in standard units

TABLE 6 PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

PARAMETER	Percent removal/addition		
	Line 1	Line 2	Total
Acidity	37.10-*	99.60-	99.80-
Conductivity	2.50+	2.50++	5.10+
Sulfate	9.00+	.00-	9.00+
Copper	5.90-	81.30-	82.40-
Chromium	33.40-	25.00-	50.00-
Lead	.00-	50.00+	50.00+
Manganese	4.50-	48.90-	51.20-
Iron ABS	84.90-	98.30-	99.80-
Zinc	.00-	98.60-	98.60-
Aluminum	10.70-	99.50-	99.50-
Nickel	20.40+	3.80-	15.80+
Magnesium	2.40-	1.70-	4.00-
Calcium	125.00+	128.80+	415.00+

* - indicates percent removal
+ + indicates percent addition

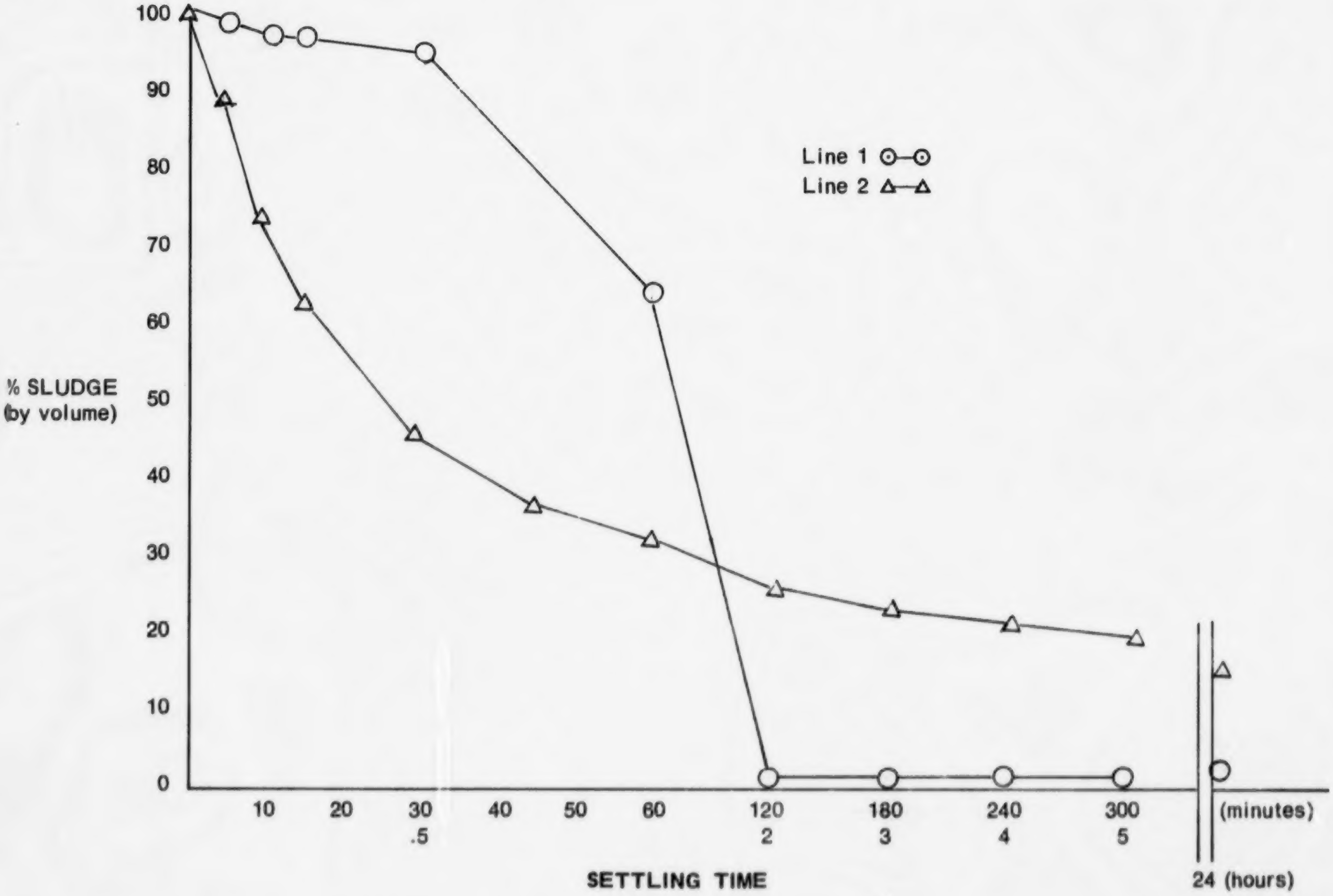


Figure 1.
SLUDGE SETTLING BEHAVIOR

WILL SCARLET WATER TREATMENT PLANT RESEARCH REPORT NO. 20

DATE March 15, 1974

I. DESCRIPTION OF RESEARCH STAGE

A. According to the revised research schedule, limestone was used as the chemical agent on both treatment lines at ten pounds per belt-foot counterpoise weight. The flow pattern was parallel (50/50), and sludge was recirculated from each treatment line to its respective rapid-mix vessel at a rate of 173 GPM on line No. 1 and 155 GPM on line No. 2. An effort was made to maintain line No. 1 effluent at pH 3.5 and line No. 2 effluent at pH 4.0.

B. For the research period February 19-20, 1974 (18.6 hours of plant operation), the following summary is submitted:

TABLE I TREATMENT DISCHARGE VOLUMES*

Units	Sludge volume	Water influent	Sludge/water ratio
	Line 1		
Gallons	193,068	1,942,956	.099
Liters	731,302	7,359,528	
	Line 2		
Gallons	172,980	1,294,560	.133
Liters	655,213	4,903,534	
	Total		
Gallons	366,048	3,237,516	.113
Liters	1,386,516	12,283,083	

*pH desired: Line 1, 3.5; Line 2, 4.0. Actual pH: Line 1, 3.3, Line 2, 3.9; influent, 2.8

TABLE 2 TREATMENT REQUIREMENT SUMMARY

	Line 1	Line 2
Alkalinity added (mg/l as $CaCO_3$)	0.00	0.00
Sludge volume (% of initial volume after 24 hours)	1.00	3.00
Treatment required (lb chemical/1000 gal influent)	5.98	13.89

TABLE 3 TREATMENT COST SUMMARY

Line	Cost Unit*	Total Weight+	Water Influent#	¢/vol §	¢/vol/ppm++
1	0.46	11,630	1,942,956	2.8	0.9
2	0.46	17,980	1,294,560	6.4	2.1
Subtotal:	--	29,610	3,237,516	-	-
Total (chemical only):		---	---	4.2	1.4
Total (operating):		---	---	9.8	3.3

* ¢/lb of chemical
+ lb of chemical
++ Gal of water treated
§ Cost, ¢/1000 gal of plant influent
# Cost, ¢/1000 gal of plant influent/1000 ppm acidity as $CaCO_3$ (b.p. to pH 8.3)

2. RESULTS OF TREATMENT PLANT ANALYSIS

   Refer to Table 4

3. RESULTS OF METAL ANALYSIS FROM THE CENTRAL LABORATORY

   Refer to Table 5

4. PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

   Refer to Table 6

5. PROPERTIES OF PLANT SLUDGE

   A. Sludge settling behavior

      Refer to Figure 1

   B. Solids content (%) of sludges

Line 1	(4,2)	6.49%
Line 2	(pH 7.0)	6.83%

TABLE 4 RESULTS OF TREATMENT PLANT ANALYSES

Parameter	Plant Influent			Line 1			Line 2		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Temperature (C)	10.8	11.4	11.1	10.5	11.7	11.1	10.4	11.5	11.1
pH	2.8	2.9	2.8	3.3	3.6	3.4	3.6	4.3	4.0
Acidity, b.p. to pH 8.3*	2900	3100	3000	2300	2600	2500	2100	2300	2200
Acidity, cold to 7.3, H_2O_2*	2300	2700	2500	1700	1900	1800	1300	1600	1500
Alkalinity*	0	0	0	0	0	0	0	0	0
Specific conductance+	3500	4600	4000	3700	4600	4200	3700	4400	4000
Iron, ferrous, ppm	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Iron, ferric, ppm	290	310	300	34	64	51	13	22	15
Sulfate, SO_4 ppm	3200	3300	3300	3400	3500	3500	3300	3500	3400

* ppm as $CaCO_3$

+ umhos/cm at 25C

TABLE 5 METAL ANALYSIS* (A.A. SPECTROPHOTOMETRY FROM CENTRAL LAB.)

Collection site	pH	Cu	Cr	Pb	Mn	Fe	Zn	Al	Ni	Mg	Ca
☐ Plant influent	2.9	0.31	0.10	0.19	86.5	343	8.86	200	3.31	250	240
☐ Line 1	3.5	0.29	0.11	0.26	86.0	74.5	9.92	190	3.95	263	490
☐ Line 2	4.0	0.28	0.06	0.26	83.0	27.5	9.92	190	4.20	259	550

*Results in mg/l; pH in standard units

TABLE 6 PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

PARAMETER	Percent removal/addition	
	Line 1	Line 2
Acidity	28.00-*	40.00-
Conductivity	5.00+	.00-
Sulfate	6.00+	3.00+[+]
Copper	6.50-	9.70-
Chromium	10.00+	40.00-
Lead	36.80+	36.80+
Manganese	.60-	4.10-
Iron ABS	78.30-	92.00-
Zinc	11.90+	11.90+
Aluminum	5.00-	5.00-
Nickel	19.30+	26.80+
Magnesium	5.20+	3.60+
Calcium	104.10+	129.10+

* - indicates percent removal
+ + indicates percent addition

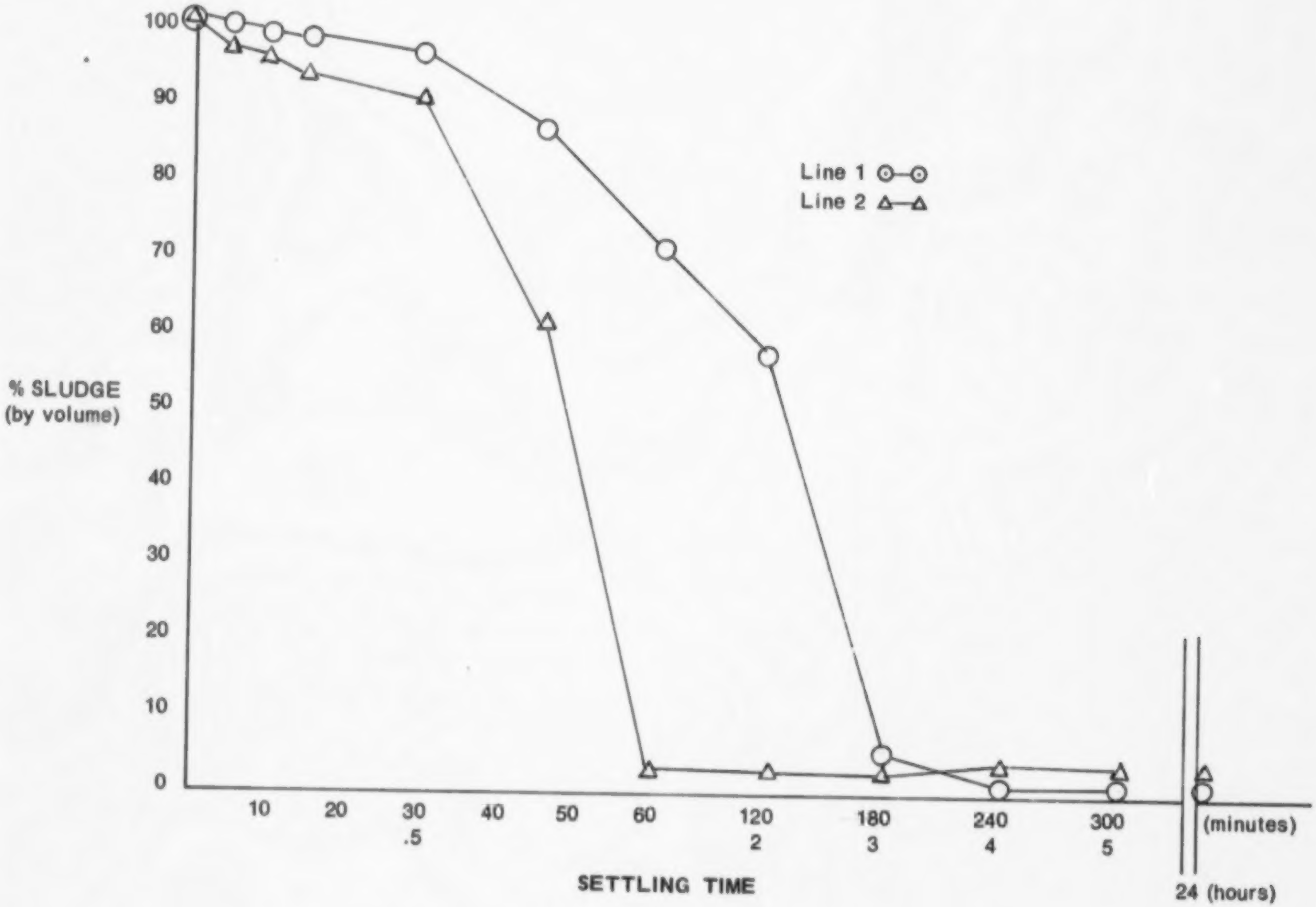


Figure 1.
SLUDGE SETTLING BEHAVIOR

WILL SCARLET WATER TREATMENT PLANT RESEARCH REPORT NO. 21

DATE March 15, 1974

I. DESCRIPTION OF RESEARCH STAGE

A. According to the research schedule, limestone was used as the chemical agent on both treatment lines at ten pounds per belt-foot counterpoise weight. The flow pattern was parallel (75/25), and sludge was recirculated from each treatment line to its respective rapid-mix vessel at a rate of 173 GPM on line No. 1 and 155 GPM on line No. 2. An effort was made to maintain line No. 1 effluent at pH 3.5 and line No. 2 effluent at pH 4.0.

B. For the research period February 21, 1974 (11.5 hours of plant operation), the following summary is submitted:

TABLE 1 TREATMENT DISCHARGE VOLUMES*

Units	Sludge volume	Water influent	Sludge/water ratio
	Line 1		
Gallons	117,294	1,376,340	.085
Liters	444,286	5,213,300	
	Line 2		
Gallons	105,090	389,860	.178
Liters	398,059	2,234,271	
	Total		
Gallons	222,384	1,966,200	.113
Liters	842,346	7,447,572	

*pH desired:

TABLE 2 TREATMENT REQUIREMENT SUMMARY

	Line 1	Line 2
Alkalinity added (mg/l as $CaCO_3$)	0.00	0.00
Sludge volume (% of initial volume after 24 hours)	1.00	2.00
Treatment required (lb chemical/1000 gal influent)	6.78	12.58

TABLE 3 TREATMENT COST SUMMARY

Line	Cost Unit*	Total Weight+	Water Influent#	¢/vol §	¢/vol/ppm‡‡
1	0.46	9,340	1,376,340	3.1	1.1
2	0.46	7,410	589,860	5.8	2.1
Subtotal:	--	16,750	1,966,200	-	-
Total (chemical only):		--	---	3.9	1.5
Total (operating):		--	---	7.5	2.8

* ¢/lb of chemical

+ lb of chemical

‡‡ Gal of water treated

§ Cost, ¢/1000 gal of plant influent

# Cost, ¢/1000 gal of plant influent/1000 ppm acidity as $CaCO_3$ (b.p. to pH 8.3)

2. RESULTS OF TREATMENT PLANT ANALYSIS

   Refer to Table 4

3. RESULTS OF METAL ANALYSIS FROM THE CENTRAL LABORATORY

   Refer to Table 5

4. PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

   Refer to Table 6

5. PROPERTIES OF PLANT SLUDGE

   A. Sludge settling behavior

      Refer to Figure 1

   B. Solids content (%) of sludges

Line 1	(pH 3.4)	16.1%
Line 2	(pH 4.1)	7.06%

TABLE 4 RESULTS OF TREATMENT PLANT ANALYSES

Parameter	Plant Influent			Line 1			Line 2		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Temperature (C)	9.4	11.3	10.4	9.7	11.4	10.4	9.7	11.4	10.4
pH	2.8	2.9	2.9	3.4	3.6	3.5	4.0	4.1	4.1
Acidity, b.p. to pH 8.3*	2500	3000	2700	2000	2500	2200	1600	2300	1800
Acidity, cold to 7.3, H_2O_2*	2200	2500	2400	1500	1900	1700	1200	1600	1400
Alkalinity*	0	0	0	0	0	0	0	0	0
Specific Conductivity+	3500	4400	3900	3700	4500	4000	3700	4300	4000
Iron, ferrous, ppm	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Iron, ferric, ppm	290	350	320	41	91	65	14	18	16
Sulfate, SO_4 ppm	3100	3200	3200	3300	3400	3400	3400	3400	3400

* ppm as $CaCO_3$

+ umhos/cm at 25C

TABLE 5 METAL ANALYSIS* (A.A. SPECTROPHOTOMETRY FROM CENTRAL LAB.)

Collection site	pH	Cu	Cr	Pb	Mn	Fe	Zn	Al	Ni	Mg	Ca
☐ Plant influent	2.9	0.29	0.13	0.13	80.0	322	7.80	200	3.08	240	230
☐ Line 1	3.5	0.30	0.09	0.26	79.0	63.0	7.09	200	3.90	249	430
☐ Line 2	4.0	0.28	0.07	0.32	79.5	15.0	7.80	185	4.41	251	525

*Results in mg/l; pH in standard units

TABLE 6 PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

PARAMETER	Percent removal/addition	
	Line 1	Line 2
Acidity	29.20-*	41.70-
Conductivity	2.50+	2.50+[+]
Sulfate	6.20+	6.20+
Copper	3.40+	3.50+
Chromium	30.80-	46.20-
Lead	100.00+	146.10+
Manganese	1.30-	.70-
Iron ABS	80.50-	95.40-
Zinc	9.20-	.00-
Aluminum	.00-	7.50-
Nickel	22.60+	38.60+
Magnesium	3.70+	4.50+
Calcium	86.90+	128.20+

* - indicates percent removal
+ + indicates percent addition

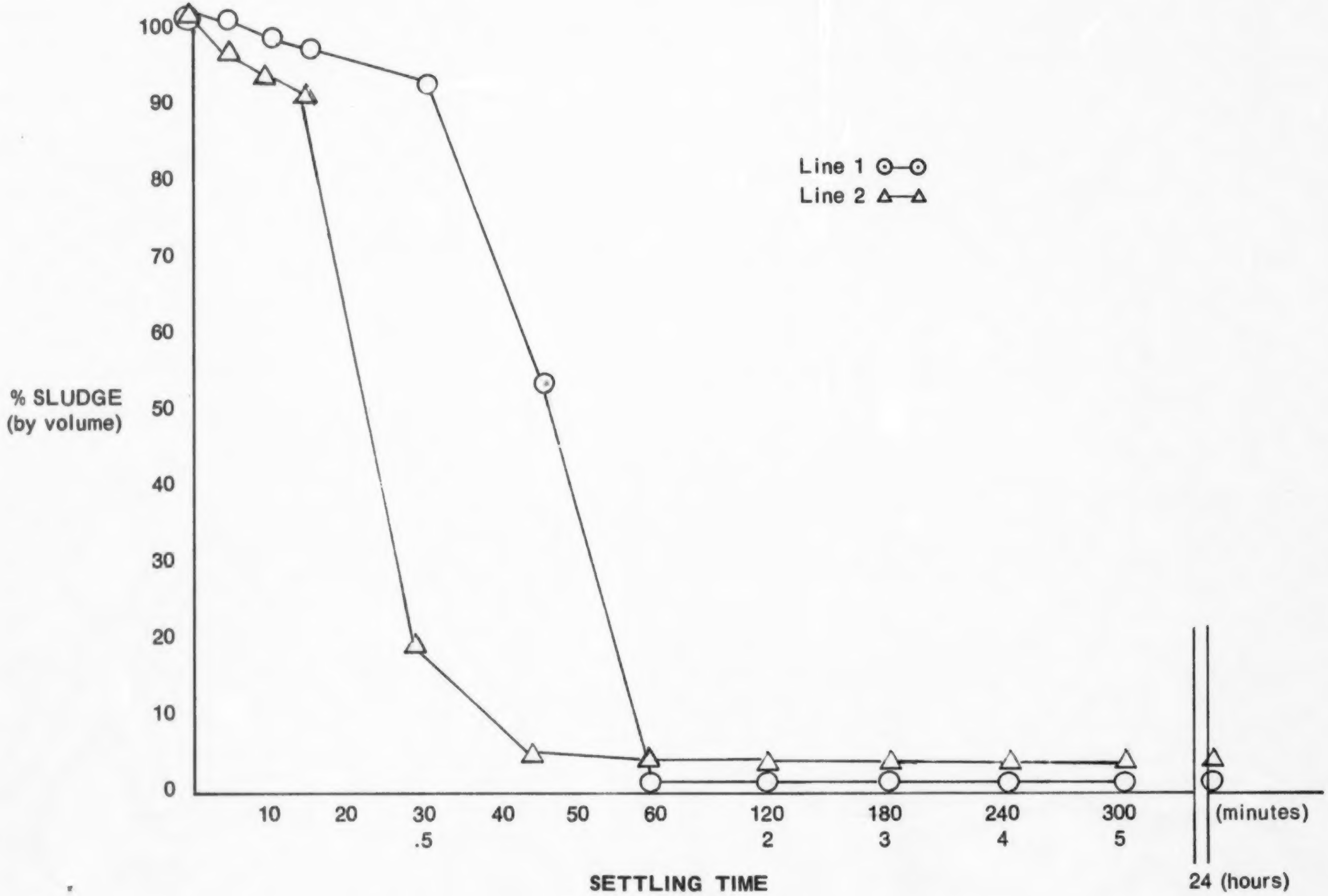


Figure 1.
SLUDGE SETTLING BEHAVIOR

WILL SCARLET WATER TREATMENT PLANT RESEARCH REPORT NO. 22

DATE March 15, 1974

I. DESCRIPTION OF RESEARCH STAGE

A. According to the revised research schedule, limestone was used as the chemical agent on both treatment lines at a counterpoise weight of ten pounds per belt-foot. The flow pattern was series at 100% of total flow, and sludge was recirculated from each treatment line to its respective rapid-mix vessel at a rate of 173 GPM on line No. 1 and 155 GPM on line No. 2. An effort was made to maintain line No. 1 effluent at pH 3.5 - 4.0 and line No. 2 effluent at the highest pH level attainable.

B. For the research period February 22, 1974 (8.5 hours of plant operation), the following summary is submitted:

TABLE I TREATMENT DISCHARGE VOLUMES*

Units	Sludge volume	Water influent	Sludge/water ratio
	Line 1		
Gallons	88,230	1,479,000	.059
Liters	334,197	5,602,156	
	Line 2		
Gallons	79,050	1,479,000	.053
Liters	299,425	5,602,156	
	Total		
Gallons	167,280	1,479,000	.113
Liters	633,623	5,602,156	

*pH desired:

TABLE 2 TREATMENT REQUIREMENT SUMMARY

	Line 1	Line 2
Alkalinity added (mg/l as $CaCO_3$)	0.00	57.00
Sludge volume (% of initial volume after 24 hours)	2.00	3.00
Treatment required (lb chemical/1000 gal influent)	5.26	14.34

TABLE 3 TREATMENT COST SUMMARY

Line	Cost Unit*	Total Weight+	Water Influent#	¢/vol §	¢/vol/ppm++
1	0.46	7,780	1,479,000	2.4	1.5
2	0.46	21,220	1,479,000	6.6	4.4
Subtotal:	--	29,000	1,479,000	-	-
Total (chemical only):		---	---	9.0	5.9
Total (operating):		---	---	16.0	10.0

* ¢/lb of chemical

+ lb of chemical

++ Gal of water treated

§ Cost, ¢/1000 gal of plant influent

# Cost, ¢/1000 gal of plant influent/1000 ppm acidity as $CaCO_3$ (b.p. to pH 8.3)

2. RESULTS OF TREATMENT PLANT ANALYSIS

Refer to Table 4

3. RESULTS OF METAL ANALYSIS FROM THE CENTRAL LABORATORY

Refer to Table 5

4. PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

Refer to Table 6

5. PROPERTIES OF PLANT SLUDGE

A. Sludge settling behavior

Refer to Figure 1

B. Solids content (%) of sludges

Line 1	(pH 4.3)	13.2%
Line 2	(pH 6.0)	27.3%

TABLE 8 RESULTS OF TREATMENT PLANT ANALYSES

Parameter	Plant Influent			Line 1			Line 2		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Temperature (C)	8.7	10.1	9.6	7.5	10.0	9.1	7.4	9.9	9.1
pH	2.9	2.9	2.9	4.2	4.3	4.3	5.9	6.1	6.0
Acidity, S.A. to pH 8.3*	1600	1700	1600	1100	1100	1100	97	120	110
Acidity, cold to 7.3, H_2O_2*	1200	1500	1300	720	830	760	64	110	92
Alkalinity*	0	0	0	0	0	0	0	0	0
Specific conductivity+	3300	3800	3500	3200	3600	3300	3400	3700	3500
Iron, ferrous, ppm	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Iron, ferric, ppm	150	160	150	32	33	33	21	28	25
Sulfate, SO_4 ppm	2400	2400	2400	3500	3500	3500	3700	3800	3800

* ppm as $CaCO_3$

+ umhos/cm at 25C

TABLE 3 METAL ANALYSIS[a] (A.A. SPECTROPHOTOMETRY FROM CENTRAL LAB.)

Collection site	pH	Cu	Cr	Pb	Mn	Fe	Zn	Al	Ni	Mg	Ca
☐ Plant effluent	2.9	0.16	0.05	0.07	49.5	106	4.96	120	2.85	182	250
☐ Line 1	4.0	0.13	0.04	0.26	50.0	34.0	4.96	100	3.62	185	425
☐ Line 2	6.0	0.05	0.05	0.03	0.39	48.0	26.5	4.61	20.0	4.08	640

[a] Results in mg/l; pH in standard units

TABLE 6 PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

PARAMETER	Percent removal/addition		
	Line 1	Line 2	Total
Acidity	41.60-*	87.90-	93.00-
Conductivity	5.80-	6.00+*	.00-
Sulfate	45.80+	8.50+	58.30+
Copper	18.80-	61.60-	68.80-
Chromium	55.60-	25.00-	66.70-
Lead	271.40+	50.00+	457.10+
Manganese	1.00+	4.00-	3.10-
Iron ABS	81.80-	22.10-	85.80-
Zinc	.00-	7.10-	7.10-
Aluminum	16.70-	80.00-	83.40-
Nickel	27.00+	12.70+	43.10+
Magnesium	1.60+	1.10-	.50+
Calcium	70.00+	50.50+	156.00+

* - Indicates percent removal
* + Indicates percent addition

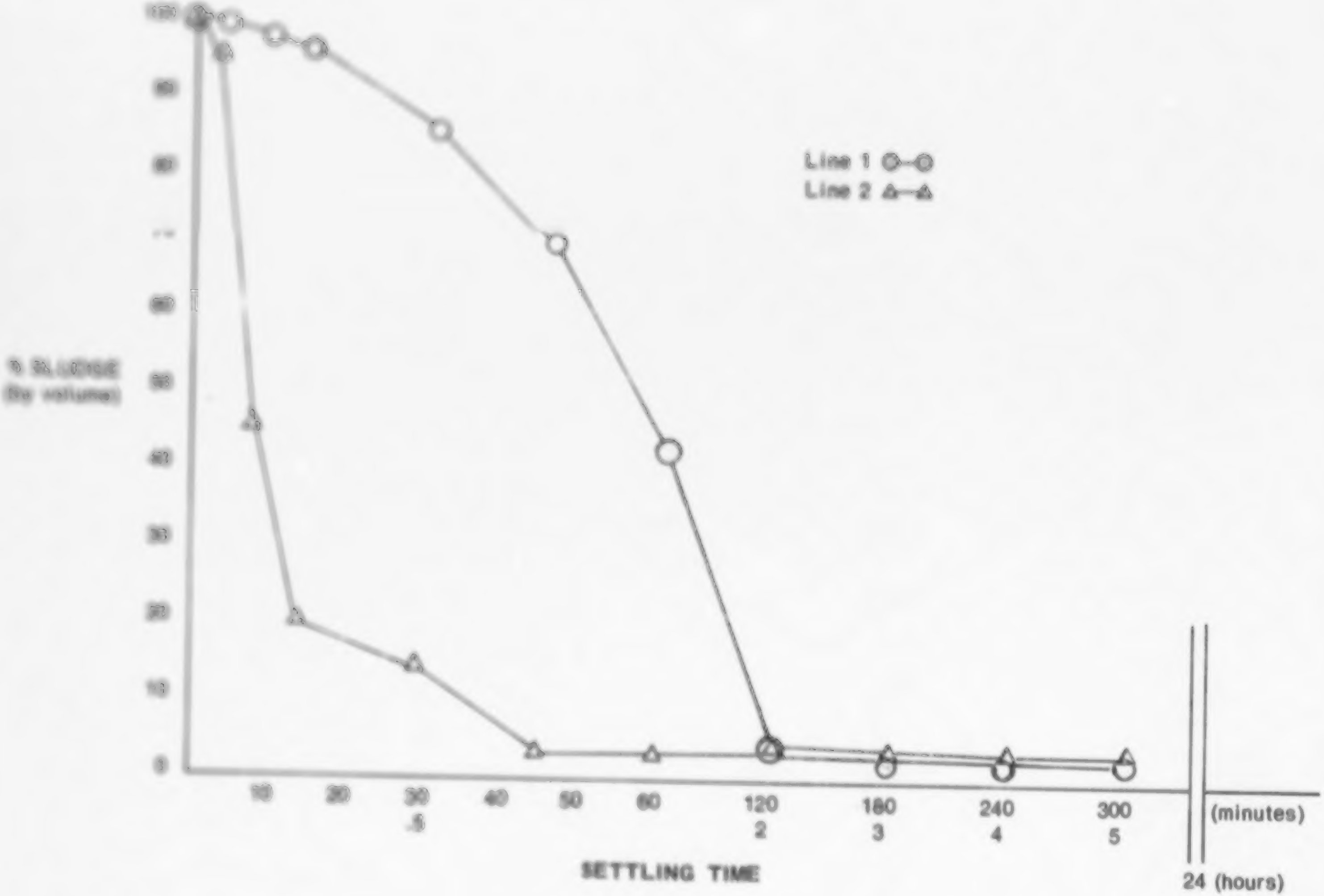


Figure 1.
SLUDGE SETTLING BEHAVIOR

WILL SCARLET WATER TREATMENT PLANT RESEARCH REPORT NO. 23

DATE March 15, 1974

I. DESCRIPTION OF RESEARCH STAGE

A. According to the revised research schedule, limestone was used as the chemical agent on both treatment lines at a counterpoise weight of ten pounds per belt-foot. The flow pattern was series at 50% of total flow, and sludge was recirculated from each treatment line to its respective rapid-mix vessel at a rate of 173 GPM on line No. 1 and 155 GPM on line No. 2. An effort was made to maintain line No. 1 effluent at pH 3.5 - 4.0 and line No. 2 effluent at the highest pH level attainable.

B. For the research period February 25-26, 1974, (23.4 hours of plant operation), the following summary is submitted:

TABLE I TREATMENT DISCHARGE VOLUMES*

Units	Sludge volume	Water influent	Sludge/water ratio
	Line 1		
Gallons	242,892	2,200,068	.110
Liters	920,026	8,333,417	
	Line 2		
Gallons	217,620	2,200,068	.099
Liters	824,301	8,333,417	
	Total		
Gallons	460,512	2,200,068	.209
Liters	1,744,327	8,333,417	

*pH desired: Line 1, 4.0; Line 2, 6.0. Actual pH: Line 1, 3.7; Line 2, 6.3; Influent, 2.9

TABLE 2 TREATMENT REQUIREMENT SUMMARY

	Line 1	Line 2
Alkalinity added (mg/l as $CaCO_3$)	0.00	85.00
Sludge volume (% of initial volume after 24 hours)	1.00	4.00
Treatment required (lb chemical/1000 gal influent)	3.70	22.86

TABLE 3 TREATMENT COST SUMMARY

Line	Cost Unit*	Total Weight+	Water Influent#	¢/vol §	¢/vol/ppm**
1	0.46	8,140	2,200,068	1.7	0.7
2	0.46	50,300	2,200,068	10.5	4.6
Subtotal:	--	58,440	2,200,068	-	-
Total (chemical only):		---	---	12.2	5.3
Total (operating):		---	---	24.8	10.8

* ¢/lb of chemical
+ lb of chemical
** Gal of water treated
§ Cost, ¢/1000 gal of plant influent
# Cost, ¢/1000 gal of plant influent/1000 ppm acidity as $CaCO_3$ (e.p. to pH 8.3)

2. RESULTS OF TREATMENT PLANT ANALYSIS

   Refer to Table 4

3. RESULTS OF METAL ANALYSIS FROM THE CENTRAL LABORATORY

   Refer to Table 5

4. PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

   Refer to Table 6

5. PROPERTIES OF PLANT SLUDGE

   A. Sludge settling behavior

      Refer to Figure 1

   B. Solids content (%) of sludges

      Line 1 (pH 5.7) 4.73%

      Line 2 (pH 8.0) 8.33%

TABLE 4 RESULTS OF TREATMENT PLANT ANALYSES

Parameter	Plant Influent			Line 1			Line 2		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Temperature (C)	6.7	10.1	8.6	6.5	10.0	8.5	6.5	10.1	8.5
pH	2.9	3.0	2.9	3.3	3.5	3.5	5.9	6.1	6.0
Acidity, b.p. to pH 8.3*	1900	2700	2300	1500	1900	1800	35	270	120
Acidity, cold to 7.3, H_2O_2*	1500	1900	1700	940	1400	1200	33	140	87
Alkalinity*	0	0	0	0	0	0	57	96	85
Specific conductivity**	3200	4000	3600	3200	4100	3700	3300	3100	3800
Iron, ferrous, ppm	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Iron, ferric, ppm	180	250	230	52	110	81	14	24	19
Sulfate, SO_4 ppm	2800	3000	3000	2800	2900	2900	3200	3500	3400

* ppm as $CaCO_3$

** umhos/cm at 25C

TABLE 3 METAL ANALYSIS* (A.A. SPECTROPHOTOMETRY FROM CENTRAL LAB.)

Collection site	pH	Cu	Cr	Pb	Mn	Fe	Zn	Al	Ni	Mg	Ca
□ Plant Influent	2.9	0.16	0.09	0.26	60.5	241	6.03	140	2.97	196	265
□ Line 1	3.5	0.17	0.09	0.26	59.5	88.5	5.67	140	3.49	197	395
□ Line 2	6.0	0.05	0.05	0.39	59.5	24.5	4.61	10.0	4.69	198	725

*Results in mg/l; pH in standard units

TABLE 6 PERCENT REDUCTION/ADDITION OF METALS AND SELECTED PARAMETERS

PARAMETER	Percent removal/addition		
	Line 1	Line 2	Total
Acidity	29.50-*	92.80-*	94.90-
Conductivity	2.70+	2.70+	5.50+
Sulfate	3.40-	17.20+	13.30+
Copper	6.20+	70.60-	68.80-
Chromium	.00-	44.50-	44.50-
Lead	.00-	50.00+	50.00+
Manganese	1.70-	.00	1.70-
Iron ABS	63.30-	72.40-	89.90-
Zinc	6.00-	18.70-	23.60-
Aluminum	.00-	92.90-	92.90-
Nickel	17.50+	34.30+	57.90+
Magnesium	.50+	.50+	1.00+
Calcium	49.00+	83.50+	173.50+

* - indicates percent removal
* + indicates percent addition

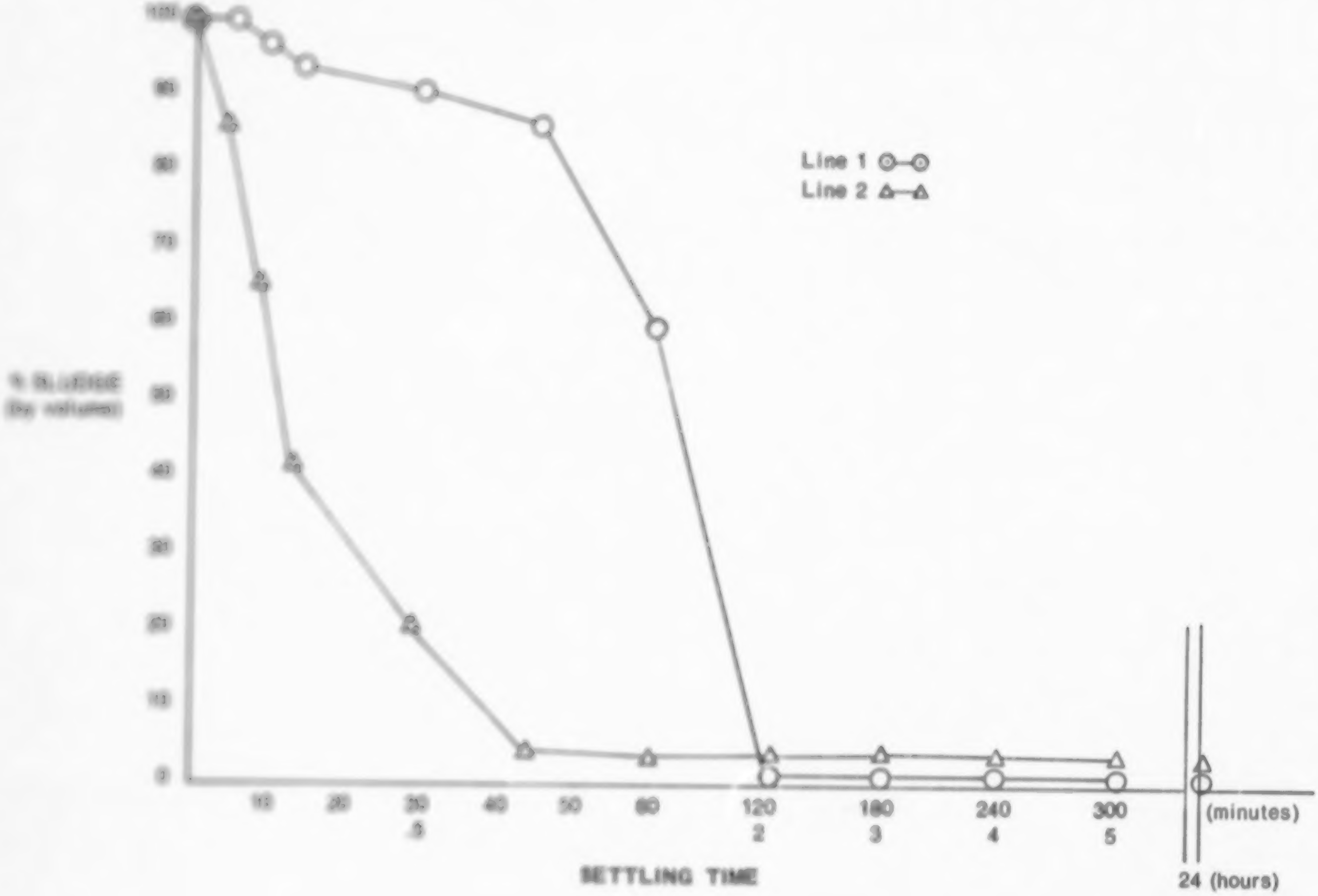


Figure 1.
SLUDGE SETTLING BEHAVIOR

APPENDIX

PART B

EFFECTS OF EFFLUENT pH ON % REMOVAL/ADDITION

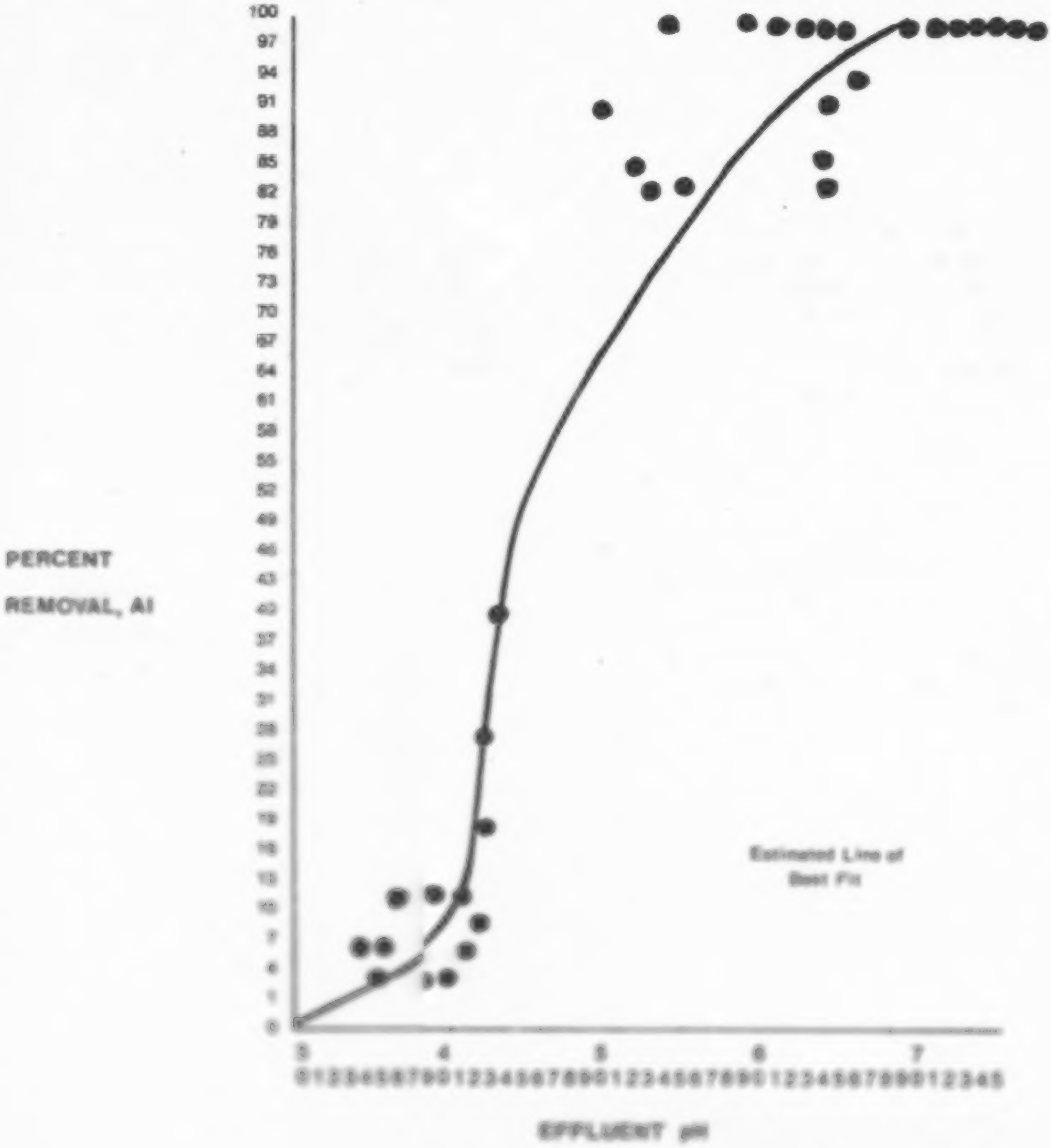


Figure
Effect of Effluent pH on Percent Removal of Aluminum Sequence for All Research Stages

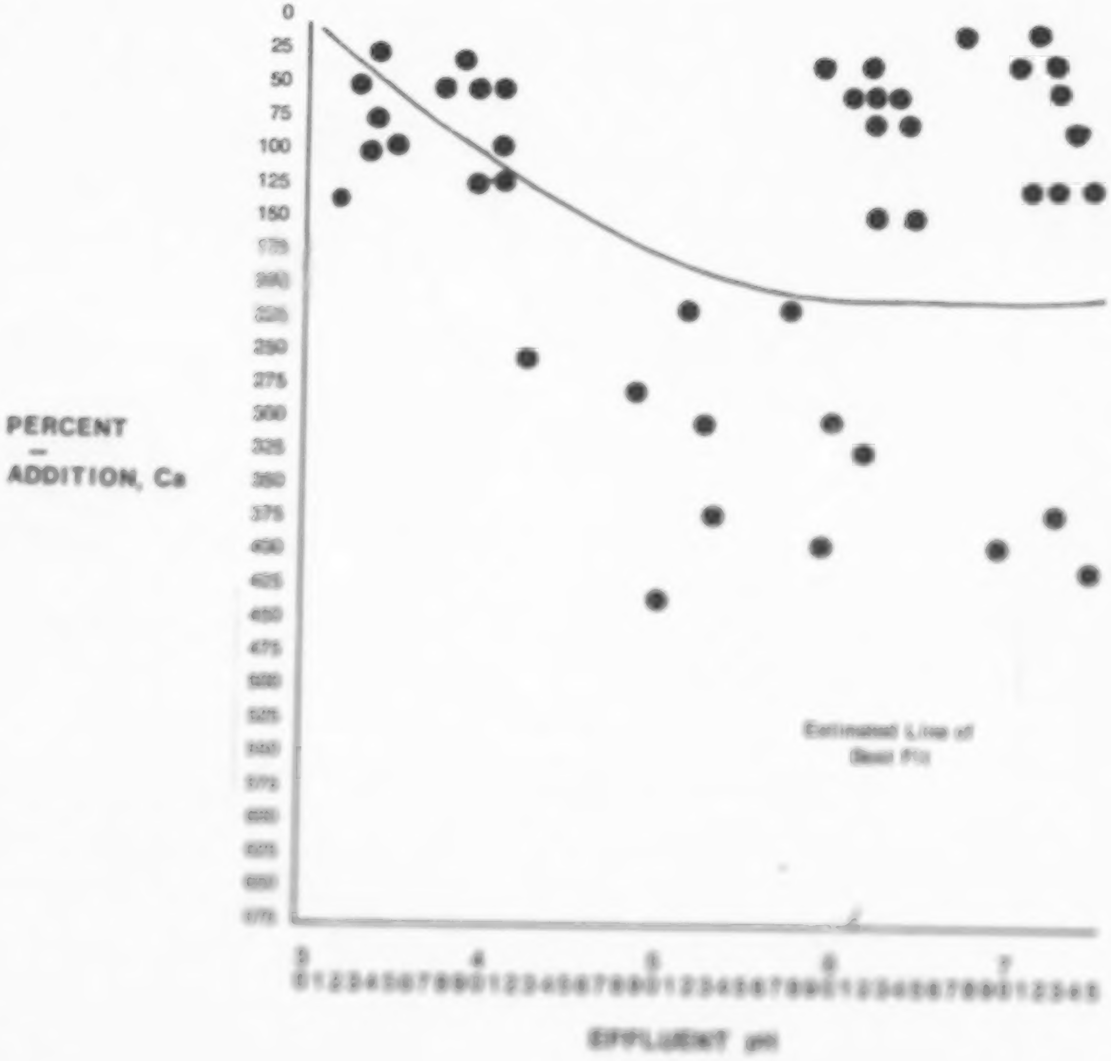


Figure
Effect of Effluent pH on Percent Removal/Addition of Calcium (Ca) for All Research Stages

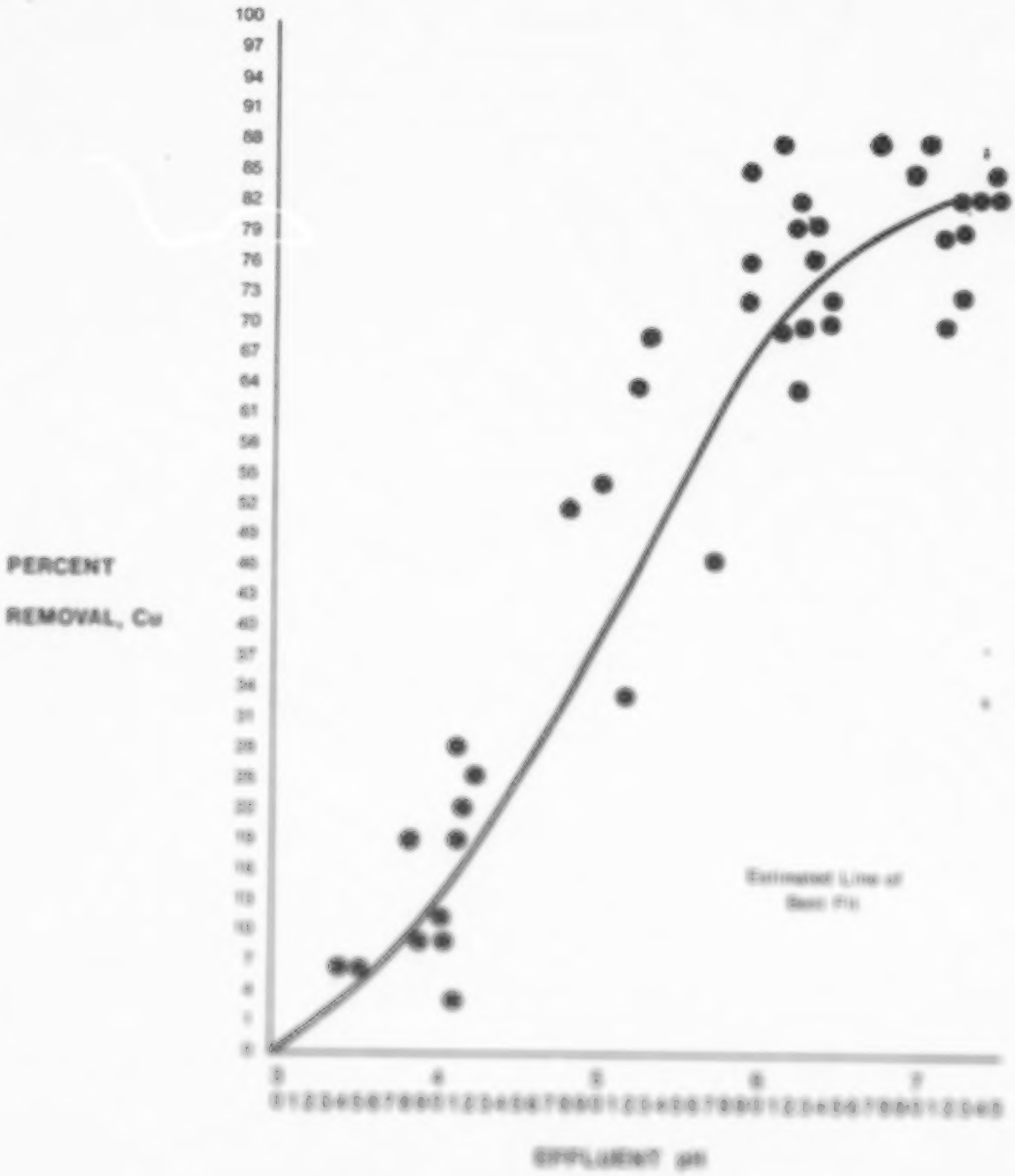


Figure
Effect of Effluent pH on Percent Removal of Copper for All
Research Stages

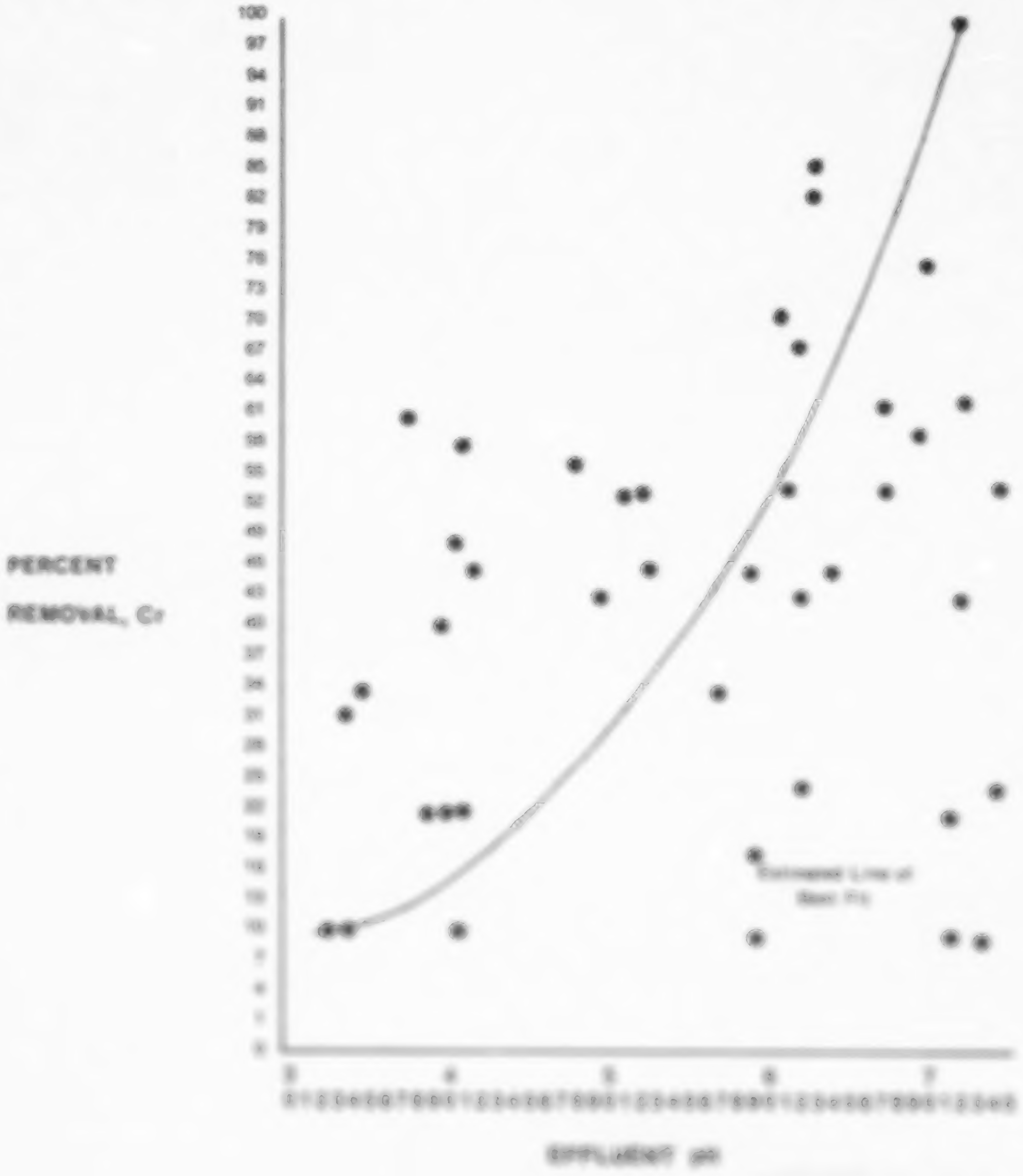
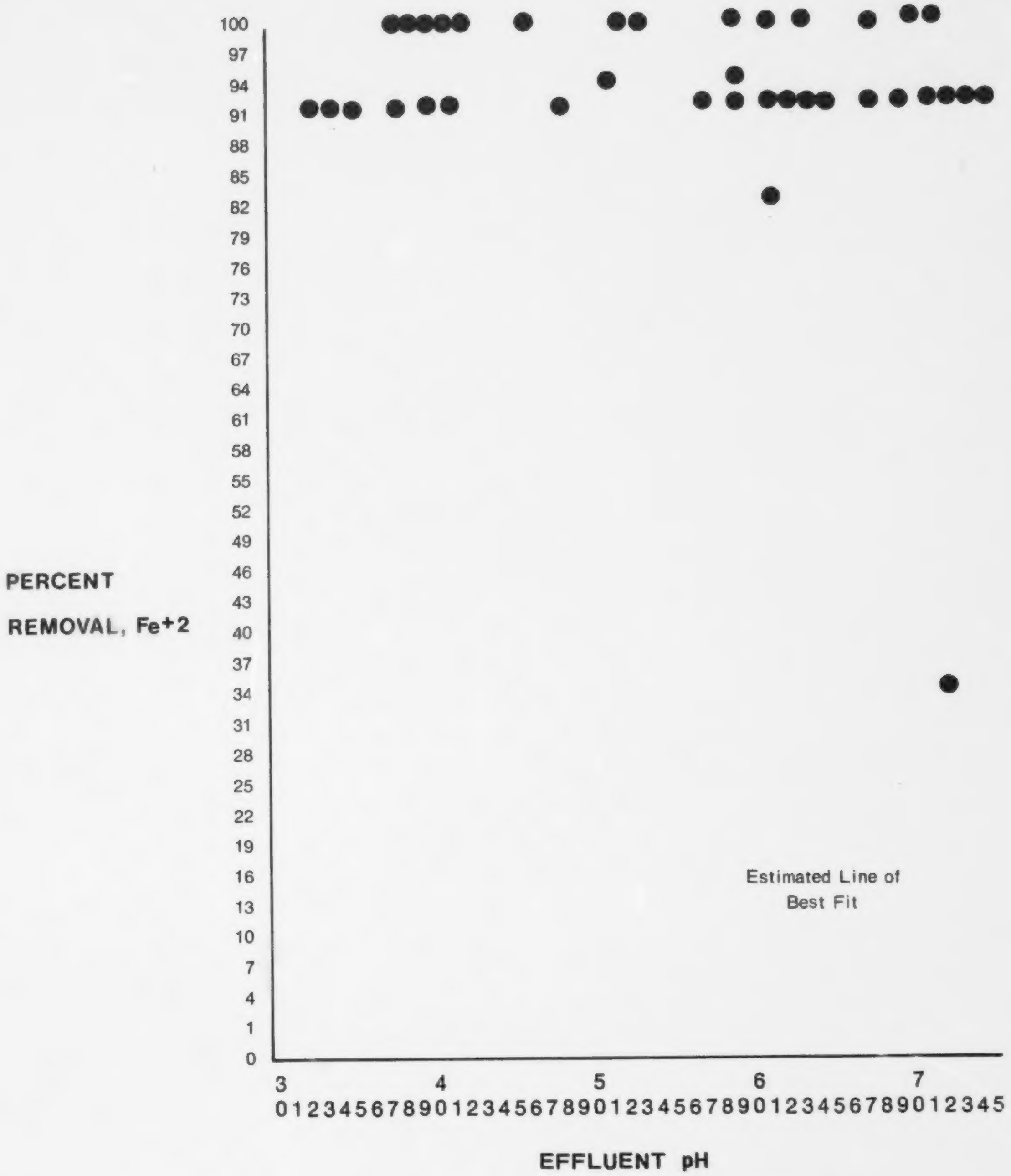


Figure Chromium

Effect of Effluent pH on Percent Removal of ~~[illegible]~~ (Cr) for All Research Stages



Figure

Effect of Effluent pH on Percent Removal of Ferrous Iron for All Research Stages

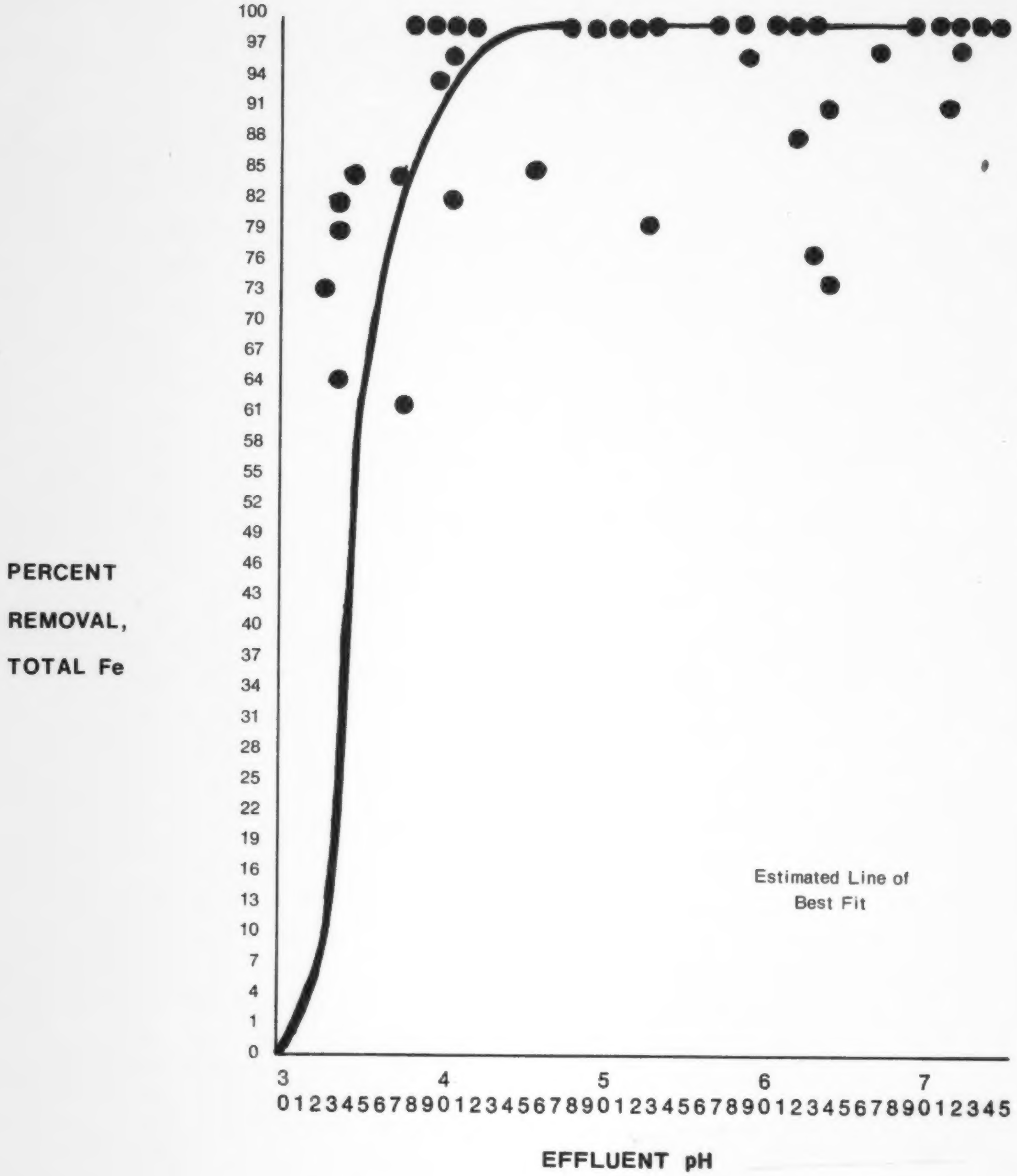


Figure
Effect of Effluent pH on Percent Removal of Total Iron for All Research Stages

APPENDIX

PART B

EFFECTS OF EFFLUENT pH ON % REMOVAL/ADDITION

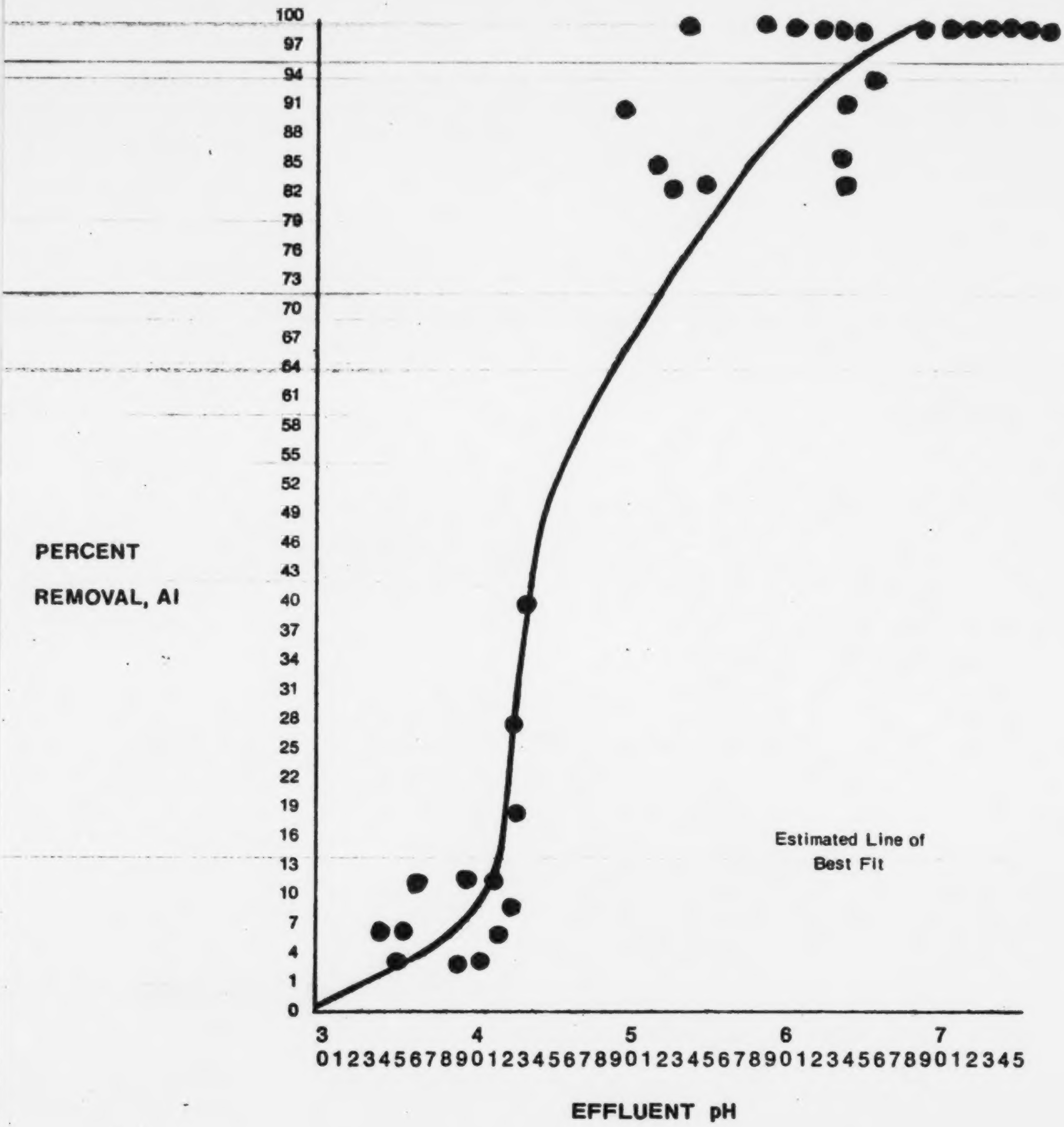


Figure
Effect of Effluent pH on Percent Removal of Aluminum Manganese for All Research Stages

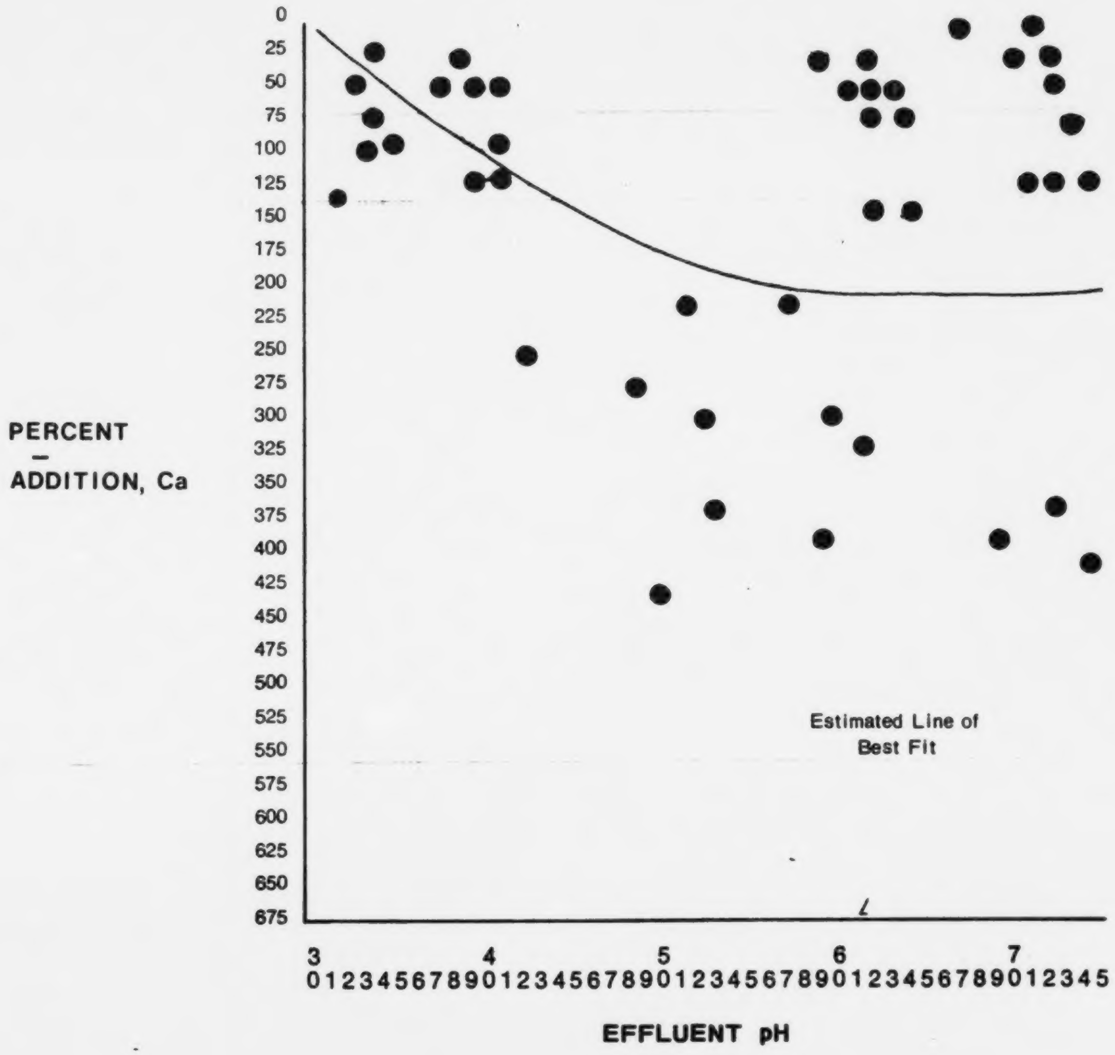


Figure
Effect of Effluent pH on Percent Removal/Addition of Calcium (Ca) for All Research Stages

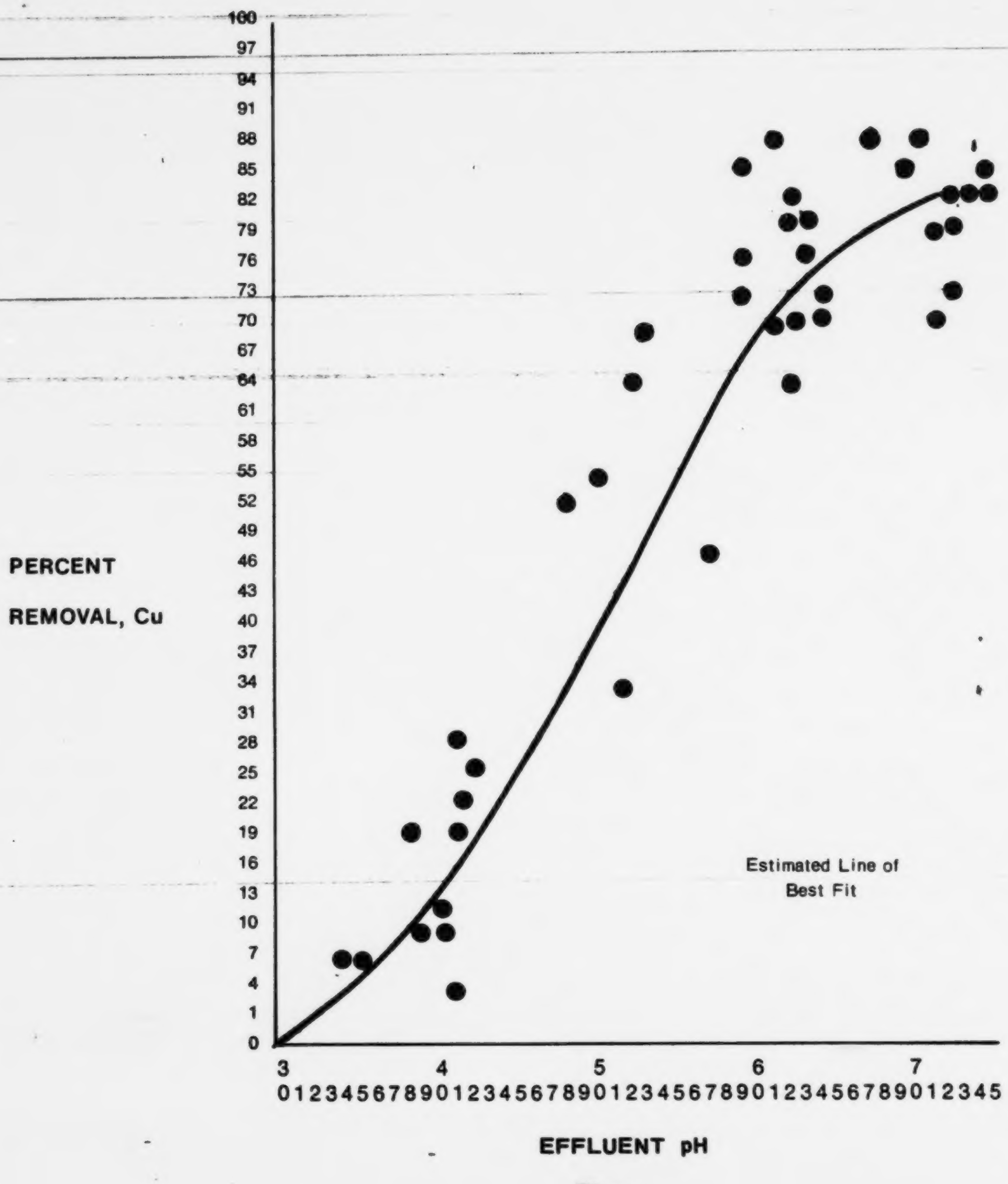


Figure
Effect of Effluent pH on Percent Removal of Copper for All Research Stages

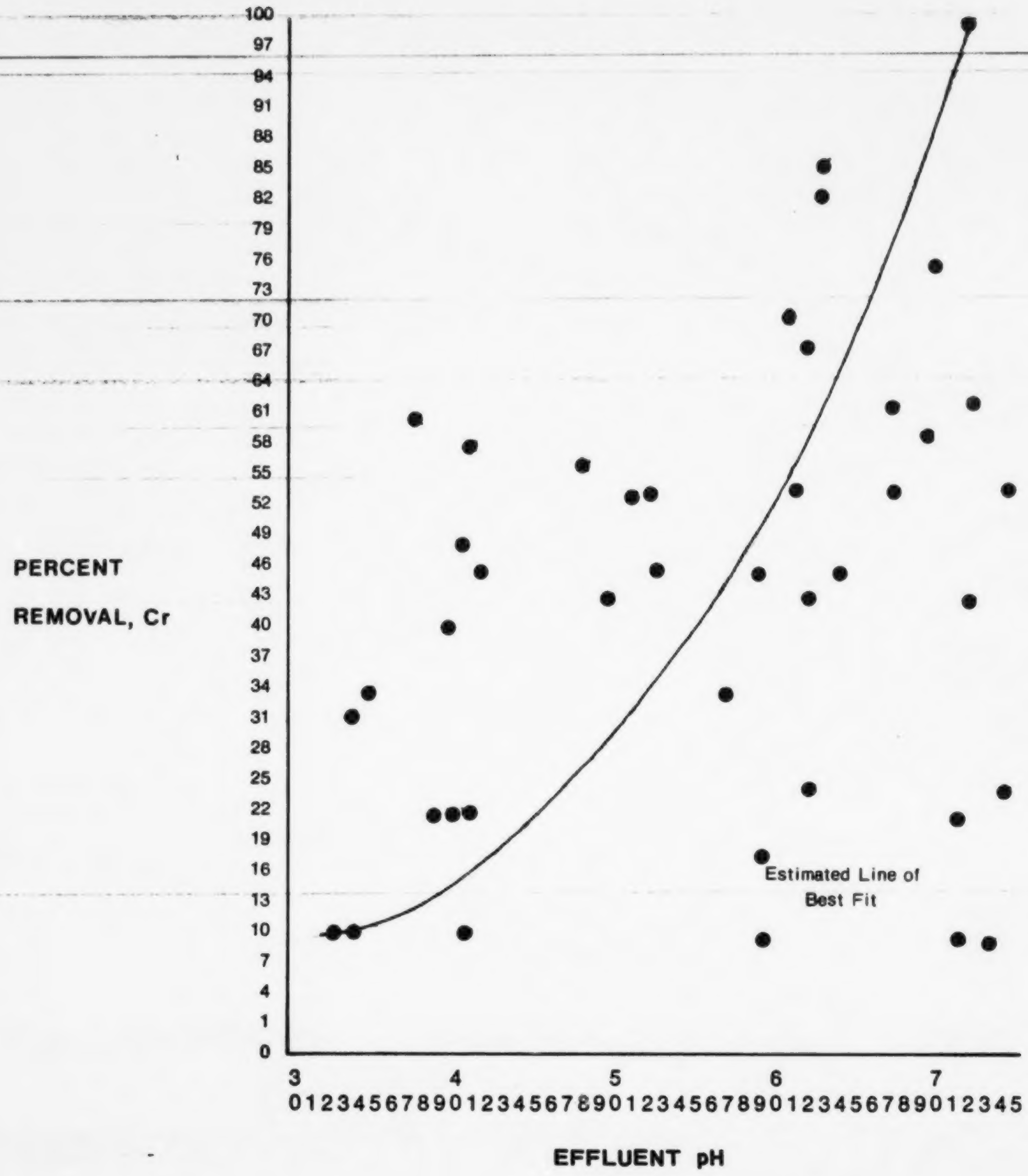
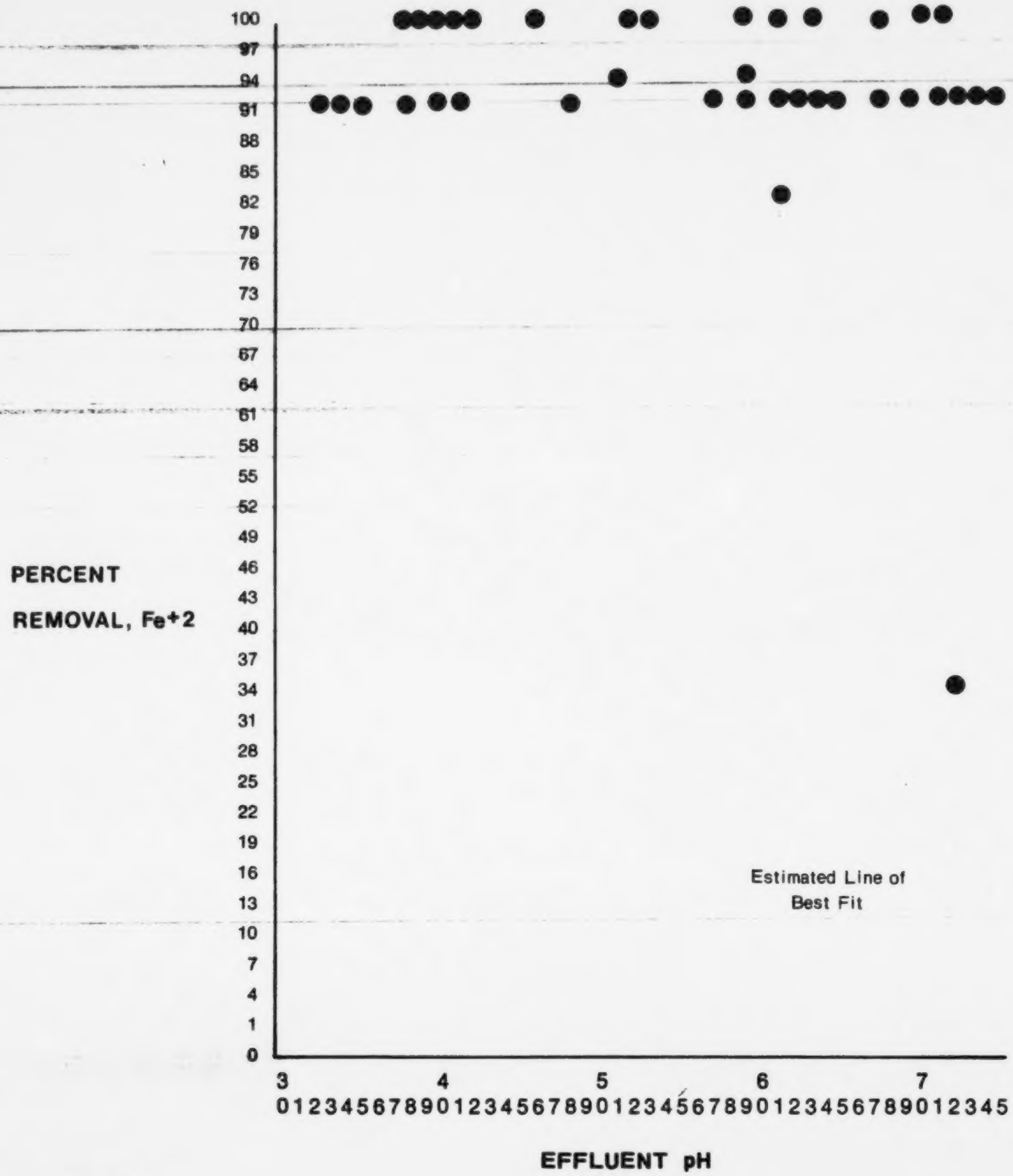


Figure
Effect of Effluent pH on Percent Removal of ~~Aluminum (Al)~~ Chromium for All Research Stages



Figure

Effect of Effluent pH on Percent Removal of Ferrous Iron for All Research Stages

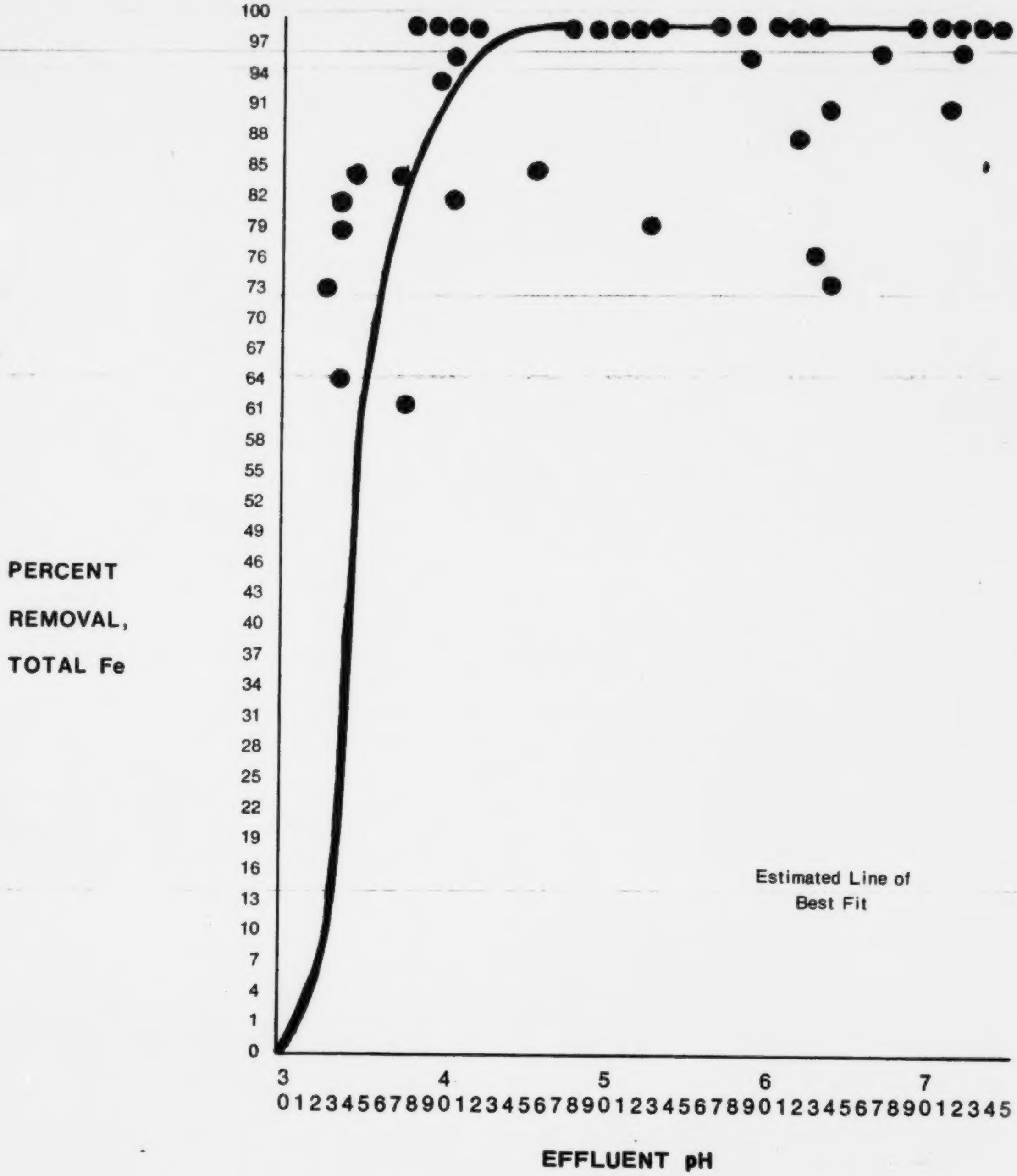
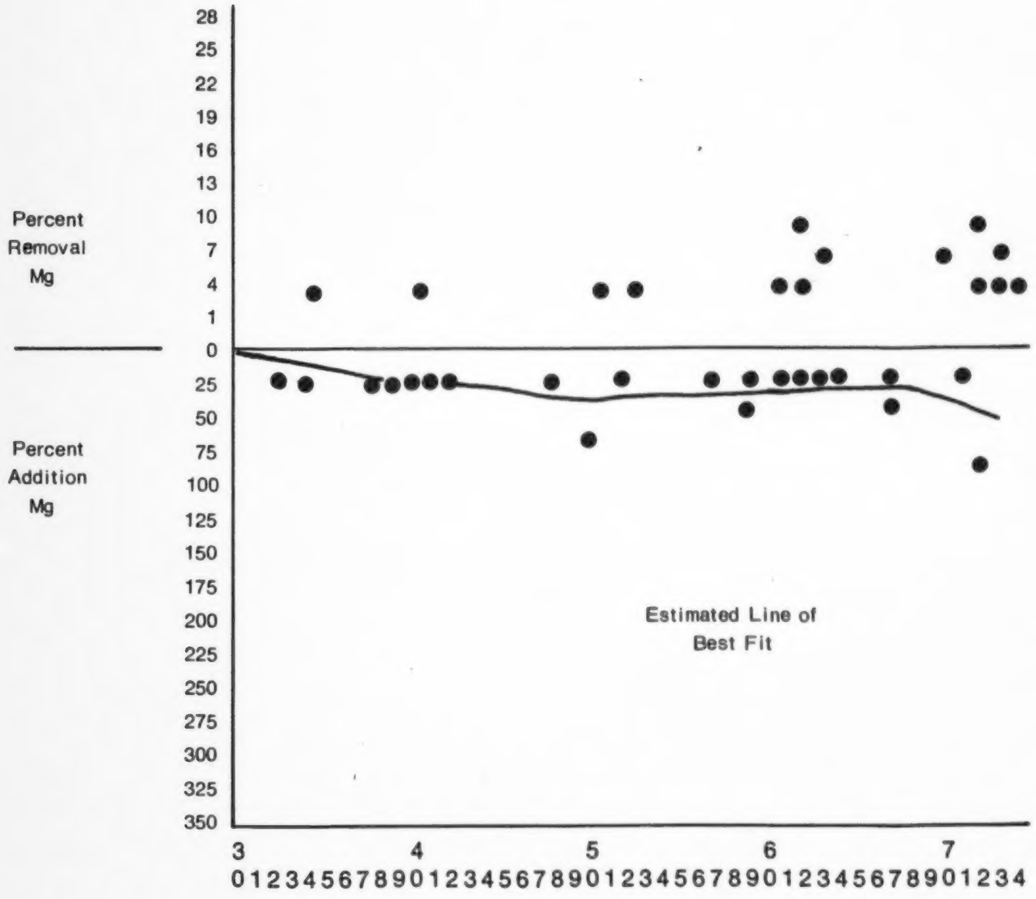


Figure
Effect of Effluent pH on Percent Removal of Total Iron for All Research Stages



Figure

Effect of Effluent pH on Percent Removal/Addition of Magnesium (Mg) for All Research Stages

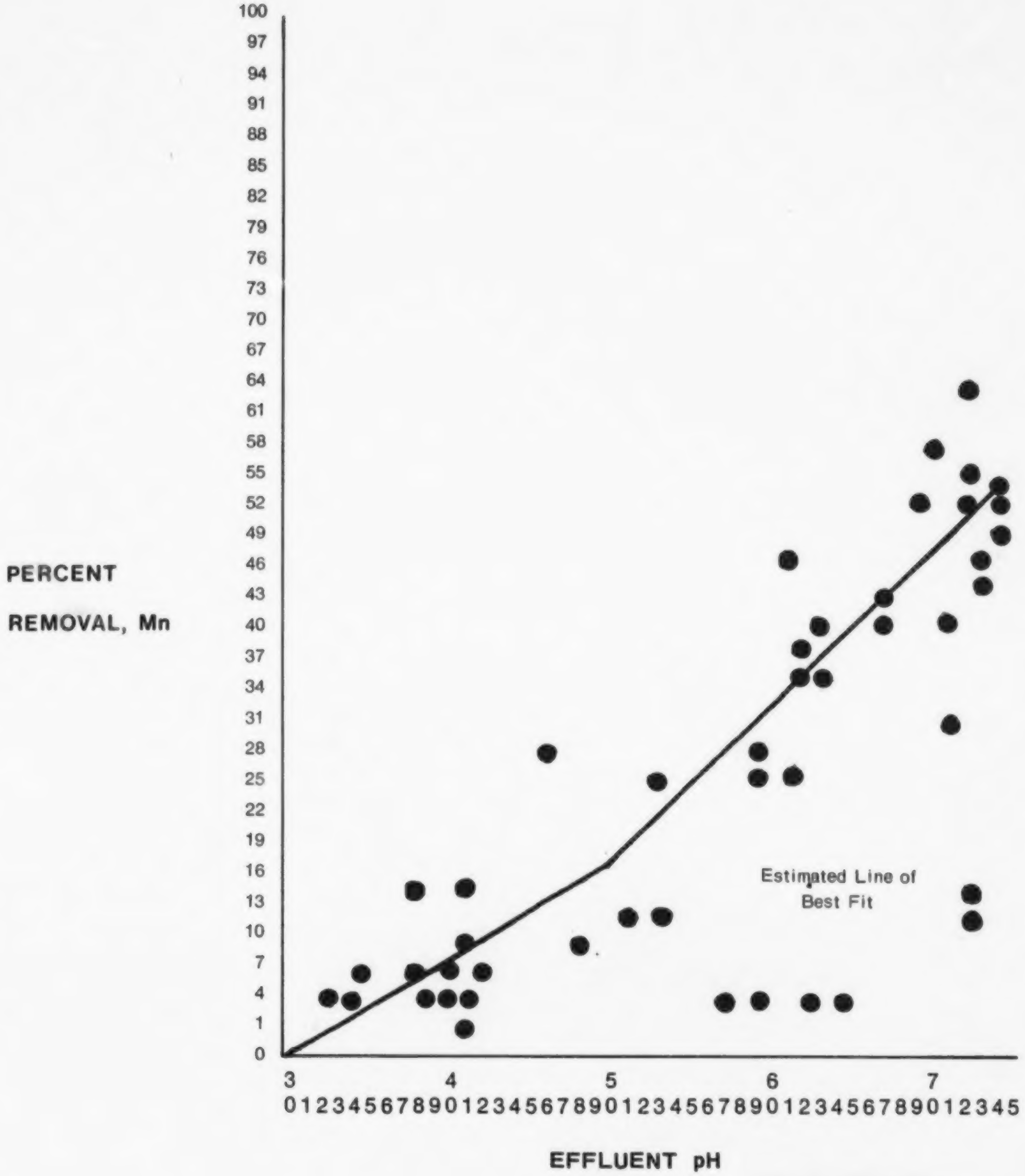
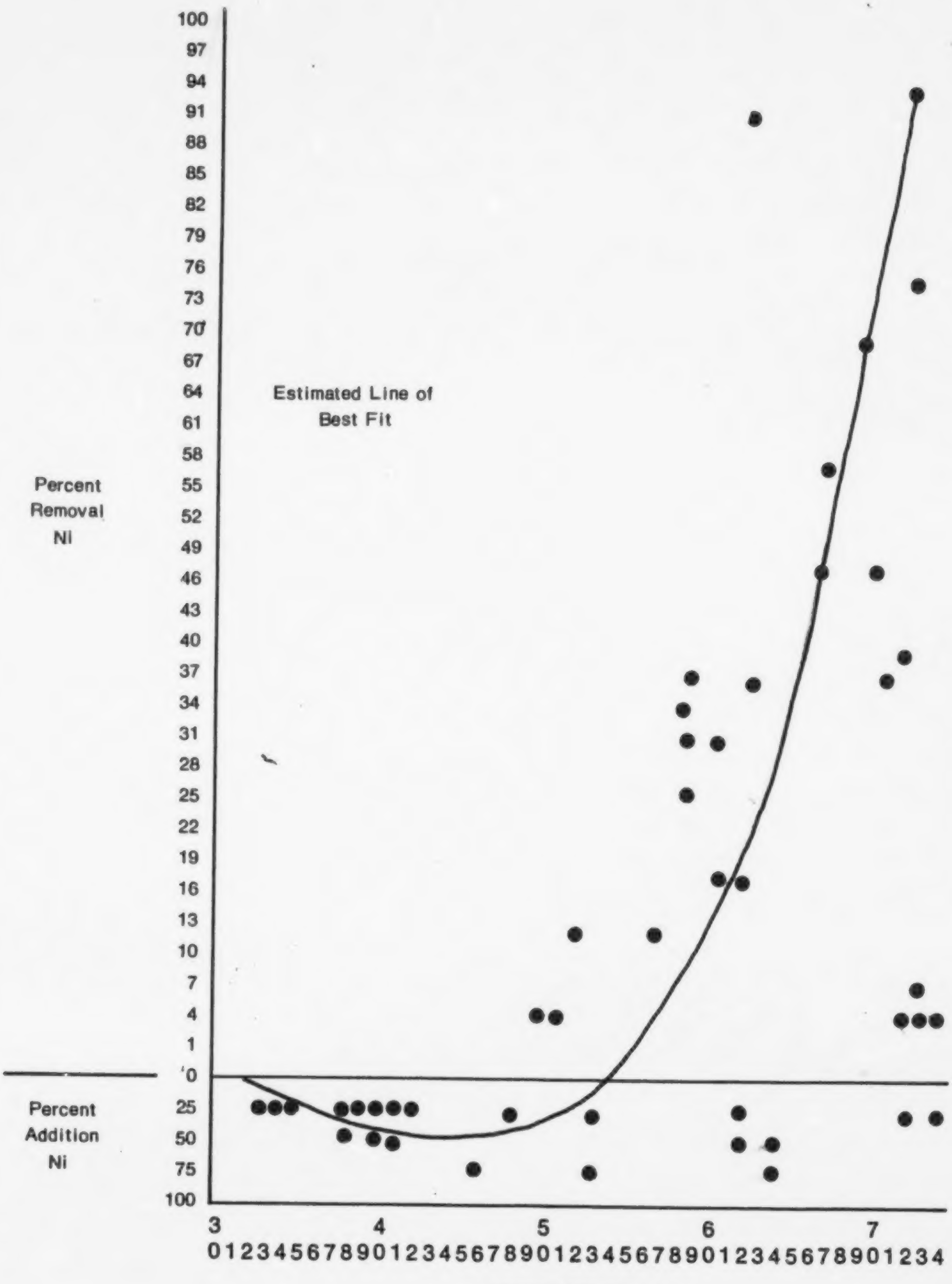
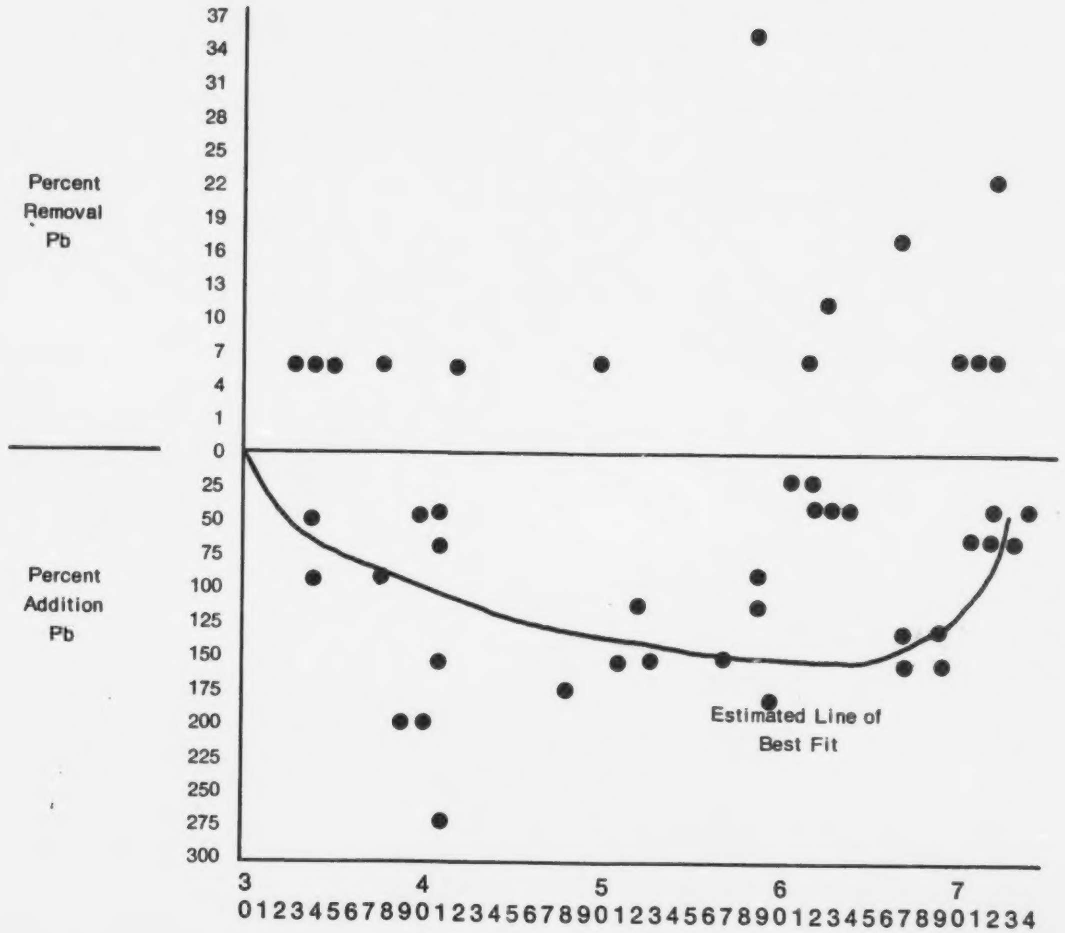


Figure
Effect of Effluent pH on Percent Removal of ~~Aluminum (Al)~~ Manganese for All Research Stages



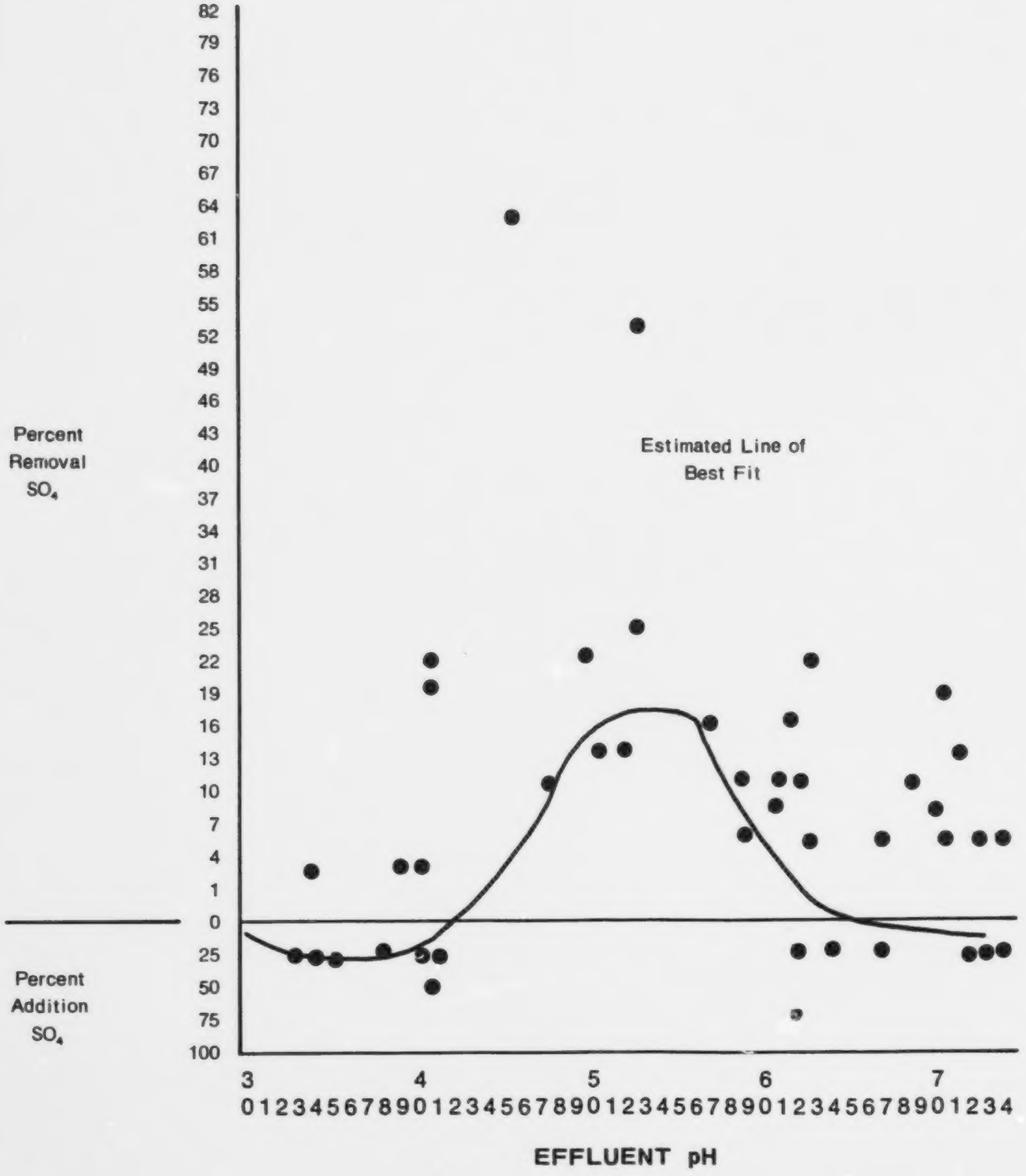
Figure

Effect of Effluent pH on Percent Removal/Addition of Nickel (Ni) for All Research Stages



Figure

Effect of Effluent pH on Percent Removal/Addition of Lead (Pb) for All Research Stages



Figure

Effect of Effluent pH on Percent Removal/Addition of Sulfate (SO$_4$) for All Research Stages

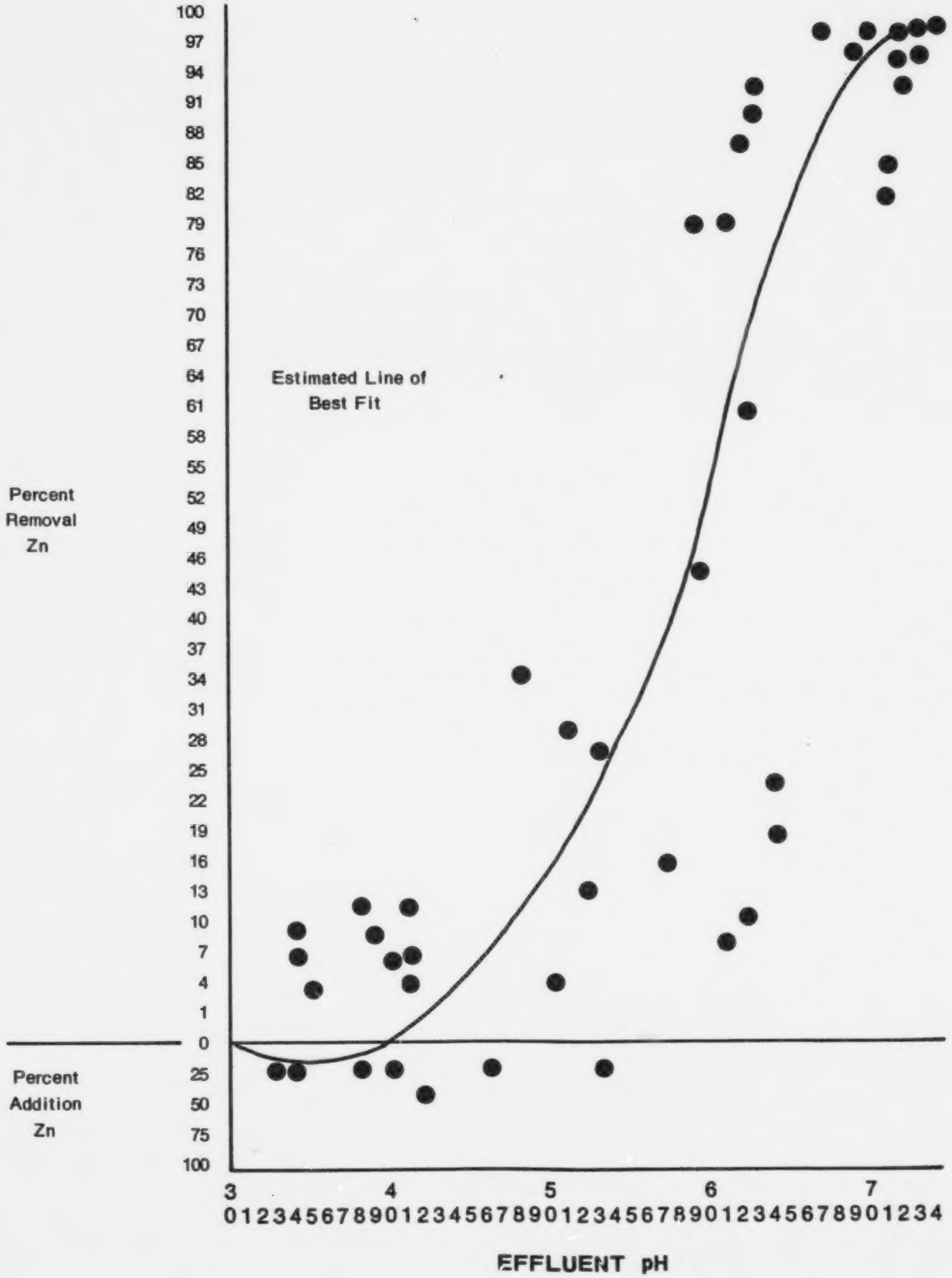


Figure
Effect of Effluent pH on Percent Removal/Addition of Zinc (Zn) for All Research Stages

APPENDIX

PART C

RESULTS OF WILL SCARLET WATER TREATMENT PLANT OPERATION at ELEVATED pH EFFLUENT LEVELS

Special operation of plant facilities was initiated to determine the optimum pH effluent levels required to remove certain constitutents. Based on previous experience, it was decided that the plant would be operated in series (two-stage) flow, 100% raw water delivery (2900 gpmi, with sludge recirculation (200 gpm) to both treatment lines. Limestone was used on the number one treatment line to an intermediate effluent pH level of 3.9. Hydrated lime was used on line number 2 to "polish" the final plant effluent to the desired pH level.

During each segment of the special investigation, the amount of chemical agent (limestone and lime) and the total raw water influent flow was closely monitored and summarized. Plant influent and final treated effluent were sampled twice during each segment of investigation for the immediate determination of pH, acidity (b.p.), acidity (H_2O_2), alkalinity alkalinity and specific conductance. Aliquots of the same were composited during each investigative sement and acid preserved for further metal analysis with atomic absorption spectrophotometry.

Table 1 presents mean water quality data of the plant influent for the period under special investigation.

Results of operational data are presented as Table 2.

Table 3 presents the results of analytical and chemical cost data during the period of special operation.

TABLE I WATER QUALITY OF PLANT INFLUENT DURING SPECIAL INVESTIGATIONS (Mean Values)

Parameter	Units	Mean Value
pH	S.U.	2.8
Acidity (b.p.) to pH 8.3	mg/l as $CaCO_3$	3000
Acidity (cold), H_2O_2 pH 7.3	mg/l as $CaCO_3$	2400
Alkalinity	mg/l as $CaCO_3$	0
Specific Conductance	umhos-cm at 25°C	4400
Sulfate (SO_4)	mg/l	4000
Copper (Cu)*	ug/l	275
Chromium (Cr)*	ug/l	111
Lead (Pb)*	ug/l	50.7
Manganese (Mn)*	ug/l	86,170
Iron (Fe)*	ug/l	300,700
Zinc (Zn)*	ug/l	2484
Aluminum (Al)*	ug/l	193,300
Nickel (Ni)*	ug/l	2317
Magnesium (Mg)*	mg/l	243.3
Calcium (Ca)*	mg/l	233.3
Cadmium (Cd)*	ug/l	101.7
Mercury (Hg)*	ug/l	10.16

* total constituent emcentration

TABLE 2 OPERATIONAL RESULTS FOR SPECIAL INVESTIGATION
WILL SCARLET WATER TREATMENT PLANT

Final effluent pH	Chemical used (Limestone) Line #1	(lb)(Lime) Line #2	Total flow (gal)	Line #1	Line #2	Line #1	Line #2
7.4	3,300	3,138	320,200	10.3	9.8	4.74	12.3
8.1	860	882	82,100	10.5	10.7	4.82	13.5
8.9	720	894	70,900	10.2	12.6	4.67	15.8
9.3	890	1,614	86,800	11.3	18.6	5.20	23.4
9.6	780	1,632	77,800	9.9	20.7	4.55	26.1
10.9	760	2,418	80,100	9.7	30.2	4.44	38.0

Raw Material Costs:
Limestone = 0.46 cents/lb. @ $9.20/ton
Lime = 1.26 cents/lb. @ $25.20/ton

Note: Variation to higher pH levels was accomplished with Rotary Hydrated Lime ($Ca(OH)_2$) on the No. 2 treatment line.

To convert lbs/1000 gals. to Kg/cum. multiply by 0.120. To convert from cents/1000 gals. to cents/cum. multiply by 0.264. To convert from gpm to liters/min., multiply by 3.785.

TABLE 3 ANALYTICAL (METAL-REMOVAL) AND COST DATA FOR SPECIAL INVESTIGATION

Parameter	Units	Plant influent (Av pH= 2.8)	Final effluent pH levels					
			7.4	8.1	8.9	9.3	9.6	10.9
Cu	ug/l	275	40	30	30	40	30	20
	% removal/addition*	-	85.5	89.1	89.1	85.5	89.1	97.8
	¢/1000 gals.	-	17.1	18.4	20.6	28.6	30.7	42.5
Cr	ug/l	111	35	70	35	35	35	35
	% removal/addition	-	69.5	36.9	69.5	69.5	69.5	69.5
	¢/1000 gals.	-	17.1	18.4	20.6	28.6	30.7	42.5
Pb	ug/l	50.7	82	86	78	93	86	98
	% removal/addition*	-	+162	+170	+154	+183	+170	+193
	¢/1000 gals.	-	17.1	18.4	20.6	28.6	30.7	42.5
Mn	ug/l	86,170	40,000	20,000	5,900	1,730	440	320
	% removal/addition	-	53.6	76.8	93.2	98.0	99.5	99.6
	¢/1000 gals.	-	17.1	18.4	20.6	28.6	30.7	42.5
Fe	ug/l	300,700	8,600	1,800	1,185	710	825	1,255
	% removal/addition	-	97.1	99.4	99.6	99.8	99.7	99.6
	¢/1000 gals.	-	17.1	18.4	20.6	28.6	30.7	42.5

* + indicates percent addition; otherwise percent removal is indicated

TABLE 3 (Continued) ANALYTICAL (METAL-REMOVAL) AND COST DATA FOR SPECIAL INVESTIGATION, APRIL 9, 1974

Parameter	Units	Plant influent (av pH = 2.8)	Final effluent pH levels 7.4	8.1	8.9	9.3	9.6	10.9
Zn	ug/l	2,484	838	153	93	0	0	0
	% removal/addition	-	70.6	94.6	96.7	100	100	100
	¢/1000 gals.	-	17.1	18.4	20.6	28.6	30.7	42.5
Al	ug/l	198,300	5,700	2,200	4,000	6,900	10,100	4,200
	% removal/addition	-	97.1	98.9	98.0	96.5	94.9	97.9
	¢/1000 gals.	-	17.1	18.4	20.6	28.6	30.7	42.5
Ni	ug/l	2,317	428	240	0	0	0	0
	% removal/addition	-	81.5	90.0	100	100	100	100
	¢/1000 gals.	-	17.1	18.4	20.6	28.6	30.7	42.6
Mg	mg/l	243.3	230	220	180	130	50	10
	% removal/addition	-	5.5	9.6	26.0	46.6	79.5	95.9
	¢/1000 gals.	-	17.1	18.4	20.6	28.6	30.7	42.6
Ca	mg/l	233.3	1,050	1,040	1,090	1,220	1,240	1,180
	% removal/addition*	-	+450	+446	+467	+523	+532	+506
	¢/1000 gals.	-	17.1	18.4	20.6	28.6	30.7	42.6
Cd	ug/l	101.7	16	4	4	7	7	4
	% removal/addition	-	84.3	96.1	96.1	93.1	93.1	96.1
	¢/1000 gals.	-	17.1	18.4	20.6	28.6	30.7	42.6
Hg	ug/l	101.16	0.60	0.35	0.13	0.08	0.04	0.06
	% removal/addition	-	94.1	96.6	98.7	99.2	99.6	99.4
	¢/1000 gals.	-	17.1	18.4	20.6	28.6	30.7	42.6

* indicates percent addition; otherwise, percent removal is indicated